A

MANUAL

OF

HUMAN MICROSCOPIC ANATOMY,

BY

A. KÖLLIKER,

PROFESSOR OF ANATOMY AND PHYSIOLOGY IN THE UNIVERSITY OF WÜRZBURG.

WITH

TWO HUNDRED AND FORTY-NINE ILLUSTRATIONS.

LONDON:

JOHN W. PARKER AND SON, WEST STRAND.

1860.

LONDON:
PRINTED BY WERTHEIMER AND CO.,
FINSBURY CIRCUS.

TO

HIS DEAR FRIEND,

PROFESSOR W. SHARPEY, Sec. R.S.

IN GRATEFUL REMEMBRANCE OF MUCH KINDNESS AND ENCOURAGEMENT,

AND

IN TOKEN OF HIGH AND SINCERE ESTEEM,

THIS WORK IS DEDICATED,

BY

THE AUTHOR.

[redacted]

PREFACE.

THE appearance of the present translation of my *Manual of Histology,* following on the excellent version issued by the Sydenham Society in 1853-54, may seem to require a word of explanation. The earlier translation, with which were incorporated various extracts from my *Microscopical Anatomy,* was from the hands of no less eminent editors than Professors *Busk* and *Huxley.* But having been printed exclusively for members of the Sydenham Society, the work has not obtained any large circulation in the English medical world. On this account, on my visit to the British Association at Glasgow in the year 1855, I was urged by several of my English friends to prepare an independent English edition, which should also have the advantage of a more compact form. After mature consideration, I resolved to act on this suggestion; and, in the same year, I succeeded in finding a publisher, *Mr. J. W. Parker,* ready to forward the work by all the means in his power. In carrying out my project, however, a considerable obstacle presented itself. The translation was executed under my own supervision by one of my pupils, who spared no pains or diligence upon it; but when submitted to English friends, on whose judgment I could thoroughly rely, it was pronounced to have followed too literally the German original. I was, therefore, obliged to abandon all idea of publishing the work in that condition. A complete revision of the manuscript, which almost amounted to a remodelling of the translation, was, however, undertaken by *Dr. George Buchanan* and another friend in England; and these gentlemen have done their part in a manner which merits my warmest thanks.

The work which I now present to the English medical public is, in the main, a condensed version of the second German edition (of 1855) of my "*Handbuch der Gewebelehre*"; but every material addition that has been made to Human Microscopical Anatomy, up to the present date, will be found incorporated in it. The book is, therefore, brought well up to the third German edition, that of 1859.

It has been my aim to adapt this Manual alike to the requirements of the Medical Practitioner and of the Student: I trust, however, that the professed Histologist will not miss from it any essential matter, although of course the book is not intended to supersede the study of memoirs on special subjects. Although England may boast of many labourers of the highest distinction in the province of Microscopical Anatomy, and although this subject, among others, is treated in a most masterly way in several important English works — I need but to instance the *Anatomy* of *Quain* and *Sharpey*, and the *Physiological Anatomy* of *Todd* and *Bowman* — still there is as yet no work in English scientific literature devoted wholly and exclusively to the detailed treatment of the Textural Anatomy of Man, as at present known. Considering, therefore, the great and acknowledged importance of this study in relation to Practical Medicine and Physiology, I venture to hope that my book may meet with a favourable reception and a friendly criticism. Should this be the case,

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and should this publication succeed in rendering any service to scientific literature in England, it will be a peculiar gratification to me, to feel that I have repaid in some measure the obligations which I owe to that country, in which I have found so many sincere friends, and have gathered so much valuable instruction.

In conclusion, I cannot refrain from recording my grateful obligations to Messrs. *J. W. Parker* and *Son*, who have not hesitated to incur the additional expense of engraving anew all the woodcuts from my original drawings, and have, in every other respect, advanced the interests of my work.

A. KÖLLIKER.

WÜRZBURG, *April*, 1860.

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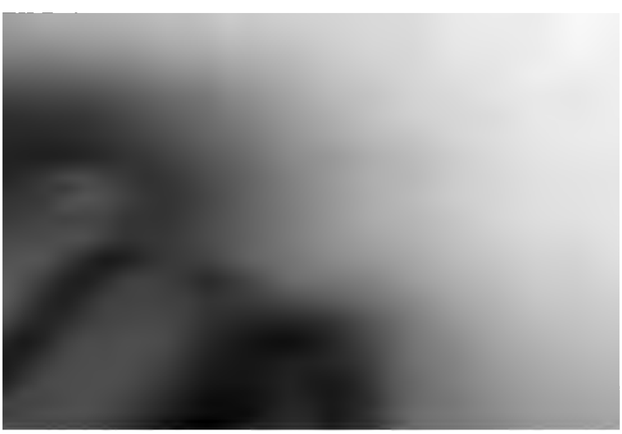

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INTRODUCTION.

§ 1. The doctrine of the elementary structure of plants and animals is the fruit of the last two centuries, and commences with *Marcellus Malpighi* (1628—1694), and *Anton van Leeuwenhoek* (1632—1723), at the period when, for the first time, high magnifying glasses, although still in a simple form, were put into the hands of investigators. The ancients and the observers of the middle ages knew nothing of the ultimate structural constituents of organism; for, although *Aristotle* and *Galen* speak of similar and dissimilar parts (*partes similares et dissimilares*) and *Fallopia* defines, still more accurately the idea of "tissues," and even attempts a classification of them (*Tractatus quinque de partibus similaribus* in Oper. Tom. ii. Francof, 1600), still the intimate conditions remained entirely concealed from these observers. Now, however brilliant the first steps of the young science were in the hands of the above-mentioned philosophers, and of *Ruysch*, *Swammerdam* and others, yet these men were not able to furnish it with a secure position, seeing that, on the one hand, investigators were still far too little acquainted with microscopical research, to be able to strive after the proper goal, and, on the other, were too much occupied with the cultivation of other branches, such as ordinary anatomy, physiology, embryology, and comparative anatomy. Thus it happened, that some isolated, and in part important, phenomena excepted, Histology made no material progress in the whole eighteenth century, and did not extend beyond an unconnected collection of individual observations (see *Fontana, Muys, Lieberkühn, Hewson, Prochaska*). It was first in 1801, that it was destined to take up its proper position among the anatomical sciences by the genius of a man, to whom, indeed, Histology is not indebted for any great discoveries, but who, better than any before him, understood how to arrange the existing materials, and bring them into relation with physiology and medicine, so that it acquired for itself independence in all future time. In fact, F. X. BICHAT's *Anatomie Générale* (Paris, 1821), is the first scientific work on Histology, and on this account forms an epoch in its history. This work, besides, attained great importance from the circumstance, that in it the tissues are not only clearly defined and treated of most fully and logically in a morphological point of view, but are also discussed in detail in their physiological functions and morbid conditions. To this great internal progress were superadded, in this century, the increasing improvements of the external aids, the microscope, and a steadily growing zeal in the investigation of nature, so that it is not surprising that Histology has, within the last fifty years, left far behind all that was accomplished in the first century and a half of its existence. From the year 1830 more particularly, discoveries followed each other in such rapid succession, that it may be regarded as truly fortunate that they, at the same time, came in such connection together that microscopical anatomy escaped the danger of losing itself in details, as in former times. It was, namely, by *C. Th. Schwann*, in 1838, shewing that animal organisms are all originally composed of cells, and that their higher morphological structure arises from these elements, that the leading thought was promulgated which united all previous observations, and also proved itself applicable to further exertions. If *Bichat* founded Histology more theoretically by the laying down and consistent working out of a system, *Schwann* has, by his investigations, established it upon facts, and thereby won for himself the second laurel in this field. That which science has done since *Schwann* down to our own time, has been indeed of the greatest importance to physiology and medicine; and in fact, of high value even in a purely scientific point of view, in so far as many things only indirectly or shortly discussed by *Schwann*, such as the origin of the cells, the signification of the cell-nucleus, the development of the higher tissues, the chemical condition of them, etc., have been further advanced; but all these discoveries are not of a kind to lead us to any material extent into a new epoch. If, without pretending to be a prophet, it be allowed me to speak of the future, the condition of Histology will not advance until we succeed in looking essentially further into the depths of organic structure, and in *perceiving the elements, of which that which we at present regard as simple, is composed.*

However, should it ever be possible to discover even the molecules which form the cell membrane, the muscular fibrillæ, the axial fibres of the nerve, etc., and to fathom the laws of their opposition and alteration during the origin, growth, and functional activity of the elementary parts, as they are now called, a new era in Histology would commence, and the discoverer of the law of cell-origin, or of a molecular theory, would be as much, or still more, extolled than the founder of the doctrine of the cellular composition of all animal tissues.

§ 2. Were we to characterise the *present position of Histology and its object* somewhat more minutely, we must not forget that that object is, properly speaking, only to study *one* of the three aspects which present themselves in the elementary parts of the body, as in the organs, namely the *form*. *Only to take cognizance of the microcospic forms, and to investigate the laws of their structure and formation, is that* upon which microscopical anatomy proceeds; but not to be a doctrine of the elementary parts in general. Accordingly, the chemical composition and functions come, properly speaking, into question only in so far as is requisite in discovering their relation to the origin of the forms and their diversity. Everything else met with in histology, concerning the functions of the fully developed elements of their chemical conditions, is either taken in from practical considerations, or is only taken as closely allied, so long as physiology does not assign a proper place to the functions of the elementary parts.

If we wish to raise Histology to the rank of a science, our first task consists in obtaining for it a broad and sure objective basis. To this end, the intimate morphological conditions of the animal organisms are to be explored in every phase, and, indeed, not only in adult animals, but also in all earlier periods, from the first development onwards. When the morphological elements are fully known, we have then to investigate the *laws* according to which they have arisen, grown, and ultimately arrived at their permanent form; during which their chemical conditions and functions cannot but be taken notice of. In order to find out these laws, the accidental and non-essential will, as in empirical sciences in general, by continued observation be separated more and more from the always present and essential, until at last a series of general empirical propositions results, for which, then, mathematical expressions or formulæ will be deducible, and thus the laws found *out*.

If it be asked how Histology responds to these desiderata, and what prospects it has for the immediate future, the answer is by no means satisfactory. Not only *does it not possess a single law*, but even the material from which laws are to be deduced is still relatively so scanty, that not even a large number of general propositions appear to be secured. Not to speak of a complete knowledge of the intimate composition of animals in general, we do not know thoroughly the structure of any creature, man not excepted, although he has so often been the subject of investigation, and, accordingly, it has not yet been possible to bring science essentially nearer to its aim. It would, however, be improper to overlook and depreciate what we possess; and it may be affirmed, that a rich treasury of facts, and even some valuable general propositions have already been won. To indicate only the most important of the former, it may be mentioned, that we possess a very satisfactory knowledge of the *fully developed elementary parts* of the higher animals, and with the exception perhaps of the elastic tissue, the tissue of the bones, and of the elements of the teeth, are sufficiently informed of the progress of their *development* also. The mode in which they unite to form organs has been less investigated; yet even in this particular much has been done of late, especially in man, whose individual organs, with the exception of the nervous system, the higher organs of the senses and some glands (liver, and vascular glands) have nearly been thoroughly investigated. If the doings in this department follow each other in the same way as heretofore, the human structure will, in a few years, be so well known, that with the aids at our command at present, nothing essential, except, perhaps, in the nervous system, will remain to be done. It is different with *Comparative Histology*, which has scarcely been commenced, and which, from the mass of material, will require not years but tens of years for its mastery. *Whoever would perform something useful in this department, must provide himself with a survey of all divisions of animals by monographs of typical forms, embracing their total structure from the first development onwards, and then endeavour to develop the laws in the manner above mentioned.*

With regard to the general propositions of Histology, the science has not advanced materially since *Schwann's* time. Nevertheless, much has been gained, inasmuch as *Schwann's* doctrines are now established in their main features. The assertion, that all the higher animals at one period consist solely of cells, and that their higher elementary parts are developed from these, stands fast, although it is not to be understood as if cells or their derivatives

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were the only possible or existing elements of animals. *Schwann's* ideas also of the origin of cells, although considerably modified and extended, have not been essentially altered, the cell-nucleus being always present as the principal agent of cell-formation and multiplication. We have advanced least with reference to the laws which prevail during the origin of the cells and higher elements, and our knowledge of the elementary processes during the formation of the organ must likewise be designated as being still very defective. Yet the proper path for clearing up these points has been taken; and a consistent investigation of the *chemical conditions of the elementary parts and of their molecular forces,* as it has been conducted by *Donders, Dubois, Ludwig,* and others, together with a more and more searching microscopical analysis of them which has been so useful in the nervous system and muscular fibres, and a *histological treatment of embryology* which has been attempted by *Reichert, Vogt,* myself and *Remak,* will certainly lift the veil more and more, and lead step by step nearer to the perfection of the science, although that may never be quite attainable.

§ 3. The aids in the study of Histology can only be shortly mentioned here. With regard to literature, the more important monographs will be found cited in the individual sections, and only the larger independent works will be enumerated here. SCHWANN'S *Microscopical Investigations on the Accordance in the Structure and Growth of Plants and Animals,* Berlin, 1839 (published in English by the Sydenham Society in 1847), deserves the first place, as the most fitting introduction to Histology. Besides, we have to mention X. BICHAT, *Anatomie Générale* (tom. iv. Paris, 1801); E. H. WEBER, *Handbook of Human Anatomy by Hildebrandt* (vol. i. *General Anatomy,* Brunswick, 1830)—an excellent work for that period, and even yet indispensably necessary, both as such and as a mine for the older literature; BRUNS' *Text-book of General Human Anatomy* (Brunswick, 1841)—very clear, concise, and good; HENLE, *General Anatomy* (Leipsic, 1841), with a classical exposition of our knowledge of the elementary parts in 1840, numerous original statements, and physiological, pathological, and historical remarks; G. VALENTIN, article "Tissue," in WAGNER'S *Handwörterbuch der Physiologie*(vol. i. 1842); QUAIN and SHARPEY'S *Anatomy* (3 vols. London, 1845—47, 6th edit. Lond. 1856)—the histological part done by *Sharpey* most excellently; R. B. TODD and W. BOWMAN, *The Physiological Anatomy and Physiology of Man* (2 vols. London, 1845—57)—based principally upon investigations of their own, very valuable; BENDZ, *Haandbog i den almindelige Anatomie* (Kiöbenhavn, 1846—47), with numerous historical reviews; A. KÖLLIKER, *Human Microscopical Anatomy or Histology* (2nd vol. *Special Histology*, 2 parts, Leipsic, 1850—54), with an exposition of the intimate structure of the human organs and systems; GERLACH, *Handbook of Histology* (2nd edit. 1853—54, Heft. i. and ii.); LEYDIG, *Histology, Human and Comparative* (Francfurt, 1857).

Besides these authorities, consult the *Jahresberichte* of *Henle*, in CANNSTATT'S *Jahresbericht*, and those of *Reichert* in MÜLLER'S *Archives*.

Pathological Histology, which is indispensably necessary for any one wishing to obtain a general point of view on Normal Histology, has but few comprehensive works to show. I may mention J. MÜLLER, *On the Intimate Structure and the Forms of Morbid Tumours* (Berlin, 1838); J. VOGEL, *Icones Histologiae Pathologicae* (Lips. 1842); GÜNSBURG, *Pathological Histology* (2 vols. Leipsic, 1845—48); LEBERT, *Physiologie Pathologique* (2 vols. Paris, 1845); J. WEDL, *Outlines of Pathological Histology* (Vienna, 1853). Besides these, the Treatises of *R. Virchow*, who of all living pathological anatomists has made the best observations, in his *Archives*, and in the *Wurzburg Proceedings*, are of the greatest importance.

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A *Collection of Microscopic Preparations*, especially of sections of bones and teeth, and of injections, is very serviceable for a minute study of Histology. Every one may with little trouble make one for himself on a small scale; for which purpose, directions will be found in the paragraphs at the end of each section of the Special Part, as also in the works cited above. Besides, microscopical preparations are to be had in exchange or on sale from *Hyrtl*, in Vienna; Dr. *Oschatz*, in Berlin; at the Microscopic Institute in Wabern, near Bern; or *Schäffer and Co.*, in Magdeburg; from *Topping*, *Smith and Beck*, *Norman*, and others, in London; and *Bourgoigne and Poteau*, in Paris. The largest private and public collections of microscopical preparations are those of *Hyrtl* in Vienna (injections); of *Harting* and *Schröder v. d. Kolk* in Utrecht (injections, sections of bone, muscles, nerves); in London, the chief are those of the College of Surgeons (animal and vegetable tissues of all kinds), *Tomes* (sections of teeth and bones), and *Carpenter* (hard structures of the lower animals). *Thiersch* and *Gerlach*, especially, in Erlangen, also possess numerous and good injections.

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GENERAL HISTOLOGY.

I.—OF THE ELEMENTARY PARTS.

§ 4. If the solid and fluid constituents of the human body are examined with the aid of magnifying powers, it is seen that the smallest elements of them visible to the naked eye, such as granules, fibres, tubes, membranes, are not the ultimate, morphological constituents, but that all contain, besides a generally distributed, perfectly fluid or pulpy, or even solid, homogeneous connecting substance, other small particles which are different in different organs and similar in similar ones. These *elementary parts*, as they are called, are of manifold kinds, some *more simple*, others *compound*. The most simple are *perfectly homogeneous*, without indicating a trace of being composed of heterogeneous particles, and are closely allied to the inorganic forms, the crystalline granules and crystals, which likewise occur in animal organisms. Others present a differentiation, consisting, as they do, of an envelope and special yet homogeneous contents; others, lastly, are still further differentiated even in the contents. The most important of all these forms which can be included in the category of *simple elementary parts*, are the cells, which are not only the starting point of every vegetable and animal organism, but, also, either as cells or after undergoing divers metamorphoses, make up the complete animal body, and, in the most simple vegetable and animal formations (unicellular plants and animals), even possess individuality. Compared with the cells, all the other simple elementary parts possess quite a subordinate importance, as far as their direct participation in the formation of the tissues and organs is concerned: on the other hand, they are undoubtedly of great moment in so far as they are almost all met with in the *interior* of the cells and participate in their vital processes in a manifold, and, in part, very significant manner.

Of the simple elementary parts which at first alone constitute the evolving animal or plant, many unite in the course of development, in such a manner that they lose their independence, and cease to exist as isolated elements. There thus arise compound forms, each of which corresponds genetically to one entire series of simple ones, and which are most fitly designated *higher elementary parts.* Such a coalescence has, hitherto, been observed only in cells with certainty, and many of the tubular and fibrous elements of the body proceed from it.

§ 5. *Fluid and solid intermediate Substances.*—Whilst in plants the elementary parts, in most cases, are directly united with each other, a special fluid, pulpy, or solid intermediate substance is very widely distributed in animals, which is often subservient to quite specific purposes, as the blood and the juices of glands, and is always ultimately derived from the blood, and more closely or more remotely related to it. When such an intermediate substance participates in the formation of the elementary parts, it may be called formative fluid, *cytoblastema,* Schleiden (from *κύτος vesicle,* and *βλαστήμα germinal material*), if it be present for the maintenance of them, it is denominated *nutritive fluid;* when, lastly, it has nothing to do either with the one or the other, it is designated *fundamental* or *connective substance.* The *cytoblastema* is usually *perfectly fluid,* as in the blood, chyle, many juices and glands, the contents of glandular follicles, and in many embryonic organs; more rarely *mucoid* and *viscid,* as in the gelatinous areolar tissues of embryos (see infra). The *nutritive fluid* occupies, in fully developed organs, the place of the formative fluid; and, except where it is contained in special canals and spaces, as in bones, teeth, and in many organs composed of connective tissue, is present in such a small quantity that it cannot be directly observed. A fundamental substance, lastly, occurs in the cartilages, and in the bones forming from these, also in the teeth, as a firm, or even bony, hard, homogeneous, granular, or even fibrous, connective mass of cellular elements, which arises partly as a secretion of the latter, partly from the blood independently of them.

The occurrence of a solid, fundamental substance, directly deposited from the blood, shows that all the solid parts of the body are not, without exception, formed from cells or in dependence upon them, as Schwann was disposed to assume. It is likewise certain, that in pathological formations such masses occur very extensively, the fibrinous exudations, especially, being capable of becoming transformed into permanent parts or tissues, without preliminary organisation, i.e. formation of cells.

A.—SIMPLE ELEMENTARY PARTS.

1.—Crystals, Granules, Filaments, Vesicles, Nuclei.

§ 6. When the simple elementary parts are compared with one another, there results an entire series of forms. The most simple of all present themselves in a form which is also met with in inorganic nature, namely, as crystals and amorphous granules; yet, in man at least, such forms are very rare as normal histological parts (otoliths, calcareous particles in ossifying cartilages), while in animals, particularly in the invertebrate (siliceous and calcareous bodies of sponges, polypi, mollusca, etc., calcareous crystals in the brain and nerves of the batrachia), and in pathological formations (crystals of hæmatine, bilifulvine, cholestearine, calcareous concretions in joints), they are frequent phenomena. On the other hand, amorphous bodies, consisting of organic substances, are very common; that is to say, in almost all animal fluids, whether contained in canals or inclosed in cells, as also in many firm tissues, there are found in various, even in enormous numbers, roundish granules, mostly of very small, scarcely measurable size. *Henle* has called them *elementary granules*, and expressed the supposition that they are vesicles. This, however, is not everywhere the case, inasmuch as it can be demonstrated that many of these corpuscles possess no envelope. To this category belong the fat drops which occur in many cells, and in numerous secretions of glands, the pigment granules of the black pigment of the eye, and of other coloured cells, the yelk granules of batrachian and plagiostomian ova, and the proteine granules found in most cells and juices of glands, as also in certain parts of the gray substance of the central nervous system. Of the pathological, yet very frequent formations, the granules of the colouring matter of the bile in the hepatic cells, the pathological granular pigment and the deposits of fat granules, as also the colloid-granules in the thyroid and other parts, and the *corpuscula amylacea* of the central nervous system, are also to be classified here, although they occasionally assume a very considerable size. All these granules are destitute of the phenomena which are observed in the higher elementary parts, as of growth from within outwards, of multiplication, of taking up and giving off material, and are, in so far, still very closely allied to the purely inorganic forms. Closely related to these formations are the *elementary fibres*, isolated finer or coarser fibres, which are developed without the co-operation of nuclei or cells by the differentiation of a homogeneous substance. Such fibres are met with in the matrix of many true cartilages, as also in many reticulated cartilages, and in many pathological formations, and may even present a growth in thickness by apposition, as in reticular cartilages.

Elementary Vesicles are likewise very frequent, and most of them are physiologically related to the elementary granules in so far as that when once formed they do not enlarge, and as they multiply neither by divisions nor by endogenous formations. The *milk-globules* which, as *Henle* first asserted, consist of the fats of the milk, and of an envelope of caseine, may with tolerable certainty be arranged under this division. The immeasurably small molecules, also, of the chyle and blood, are, according to *H. Müller's* investigation, fat globules with a proteine envelope, and similar vesicles may also occur in most other fatty and albuminous fluids. That is to say, since the discovery of *Ascherson* (MÜLLER'S *Archiv.* 1840, p. 49), that whenever fluid fat and fluid albumen are shaken together, all the fat-drops formed become surrounded with a delicate envelope of albumen, it is more than probable that wherever in the body fat and albumen come in contact in a fluid condition, similar vesicles are formed.

The elements occurring in the yelk of certain animals form a peculiar group of elementary vesicles. They are best known in the yelk of the fowl, in which the globules of the proper yelk-substance and of the vitelline cavity, are, as *Schwann* discovered, all vesicles, although they have not the importance of cells. The membranes of these yelk-vesicles are exceedingly delicate, and consist of a proteine compound; the contents are fluid albumen in which, in the globules of the vitelline cavity, there usually lies a large parietal, in the others, numerous larger and smaller fat-drops. The development of these vesicles probably proceeds from the fat-drops, as in other elementary vesicles, from which, however, they are distinguished by their possessing a very distinct growth, and undergoing metamorphoses in their contents, seeing that, in many, the number of the fat-drops increases more and more with age. Similar vesicles can also be demonstrated in the yelk of fishes, crustaceous animals and spiders, and, as in birds, have only a transitory importance, inasmuch as they are not employed directly in the formation of the body of the embryo, but only serve as nourishment for it. Lastly, *free nuclei* are met with in some places, as in the wall of the vesicles of the thymus, and in the rust-coloured lamina of the cerebellum.

With regard to the mode of the formation of "Ascherson's vesicles," as they are called, *Wittich* has quite recently furnished some information. According to *Wittich*, whenever oil and albumen come in contact, a part of the fat is saponified by the alkali combined with the albumen; by these means, the layer of albumen lying next to the oil (because poorer in alkali), is rendered insoluble, and precipitated as *Ascherson's* "Haptogen Membrane," as it is called.

[illegible] and not a physical, [illegible] however, *Harting* [illegible]-cell from [illegible] certainly [illegible] with water [illegible] Besides, [illegible] chemical influence, [illegible] produce albumen- [illegible] membrane: and by [illegible] as has been observed [illegible]

[illegible]

§ 7. [illegible] elementary cells or nuclear cells, [illegible] — [illegible] of a line in [illegible] which a special *envelope*, [illegible] and *contents* are to be [illegible] The latter always consist of fluid and of formed particles of this or of that kind, and of a special roundish body, [illegible] which again contains fluid and a still smaller corpuscle, [illegible] in its interior. These cells, which are to be considered as being endowed with special vital powers, and capable of taking up and consuming matter, as well as of growth and of multiplication, [illegible] not only solely constitute the body of the higher and of most of the lower animals in the first periods of life, but also almost solely produce the higher elementary parts of the fully formed body. Nay, even in fully grown animals, the elements are met with in very many places in the simple condition of cells; and, as such, participate more or less, often quite decisively, in the organic functions.

§ 8. A closer inspection of the condition of the cells shows the following. Their *fundamental form* is that of a sphere or lens, which belongs to all cells in their first period of life, to many, as especially those situated in fluids (blood corpuscles and others), constantly. The following forms appear more rarely: 1. The polygonal (pavement epithelial cells). 2. The conical or pyramidal-shaped (ciliated epithelium). 3. The cylindrical (cylindrical epithelium). 4. The fusiform (contractile fibre-cells). 5. The squamous (epidermic plates). 6. The stellate (nerve-cells). The size of the cells descends on the one hand, as in many cells, the blood-cells, etc., to 0·002—0·003 of a line, and attains on the other, as in the cysts of the semen and the ganglionic globules, the size of 0·02—0·04 of a line. The largest animal-cells are certain gland-cells of insects, which, according to *H. Meckel*, measure up to 0·1 of a line; the yelk-cells or ova, especially of birds and amphibia, and some animals consisting of a single cell which, like certain gregarinæ, attain 0·7 of a line.

The membrane of cells is mostly very delicate, smooth, scarcely capable of being isolated, and bounded by simple outlines; more rarely of considerable firmness and measurable thickness. In some places where it is thicker it distinctly presents pores; and it is very possible that such pores are a very widely distributed phenomenon. In the interior of cells, there are *constantly* found, at a certain period, one or several *nuclei*, besides fluid and granules in varying proportions and of different natures. Cells which only contain fluid are rare (fat-cells, blood-cells, cells of the chorda), and it is colourless or reddish; the majority contain, besides, other corpuscles (elementary granules, elementary vesicles, perhaps also crystals) in greater or less numbers; young cells, as a rule, contain few granules, while older ones have many, which are very often more densely grouped around the nucleus, or only occupy a single place (coloured ganglionic globules).

The *chemical* composition of cells is still very obscure. The contents possess, in the majority of cells, certain universally distributed materials, which occur dissolved in the nutritive fluid or in the cyto-blastema, such as water, albumen, fat, extractive matters, and salts; a nitrogenous substance, precipitable by water and diluted acids, is very widely distributed. This substance resembles mucus, and renders the microscopical examination of tissues very difficult, causing them to appear turbid and granular instead of clear and bright. Many cells contain other compounds, as those of the liver, blood, etc. The *cell-membranes* consist of a nitrogenous substance, which, in young cells, is undoubtedly a proteine compound, as may be concluded from their solubility in acetic acid (in part even without heat), and in diluted caustic alkalies. Subsequently, the membrane in many cells becomes insoluble, but is far from being so in all (e. g., in the blood corpuscles, deepest epidermic and epithelial cells, and the cells of glandular follicles), and occasionally approaches in texture the substance of the elastic tissue.

The *Cell Nucleus* is a spherical or lenticular crystalline, or yellowish body, measuring on an average 0.002—0.004 of a line, rarely attaining 0.01 — 0.04 of a line, as in ganglionic globules and ova. All nuclei are vesicles, as *Schwann* supposed, and as I recognised as a general and original formation in embryos and adult animals. Their envelope is, in the smaller ones, very delicate, and appears as a simple dark fine line; in the larger it is thicker, even of measurable thickness, and bounded by double borders, as in the nuclei of ganglionic globules, of ova, and of many embryos. The *contents* of the nuclear vesicles, apart from the nucleolus, almost invariably consist of a clear or slightly yellowish, never dark, fluid, in which the *same dark granules are perceptible by water and acetic acid, as in the cells*; on which account, even the nuclei never have their natural homogeneous bright appearance in the usual methods of investigation. More rarely, the nuclei contain formed contents, as the special granules in ova, termed germinal spots, as also in the fat-cells of *Piscicola* (*Leydig*). With regard to the chemical character of nuclei, we have only this much to say, that their membranes are nitrogenous, and in general do not differ materially from the substance forming the younger cell-membranes; still they dissolve more slowly in alkalies, and are but little attacked by diluted acetic and mineral acids: in the latter character this membrane approaches the elastic tissue, from which, however, it is *very essentially* distinguished, by its ready solubility in alkalies. Nuclei, according to my observations, are found throughout in all cells of embryos and adults as long as the cells are still young. Usually there is met with, in each cell, but one nucleus, except when it multiplies: in this case, two or more nuclei appear, according to the number of cells about to be formed. In certain cells, a greater number of nuclei are met with; thus, in those of the semen, 4, 10, to 20, and more; as also in those of the ependyma of the canalis medullæ spinalis, in those of the supra-renal capsules, and of the hypophysis, in the hepatic cells of embryos, those of the fœtal marrow, and others. That nuclei also occur *free*, and take part in the formation of certain tissues, has been already mentioned.

Nucleoli are round, sharply outlined, generally dark bodies, similar to fat-granules, measuring on an average 0·0010—0·0015 of a line. Frequently they are almost immeasurably small; and in embryos, in the germinal vesicles of ova, as germinal spots, and in ganglionic globules attain to 0·003—0·01. Probably they are everywhere vesicles, as may be inferred from their distinctly circumscribed forms, and their resemblance to elementary vesicles, as well as the circumstance that in certain cells, particularly in ova and ganglionic globules, a larger or smaller cavity, filled with a clear fluid, is developed in them. The *chemical* composition of nucleoli is unknown. Their external aspect, their resemblance to elementary vesicles, their disappearance in caustic alkalies, and their insolubility in acetic acid, would imply that they are composed of fat; the membranes, as in the elementary vesicles, may be a proteine compound. Nucleoli occur in the great majority of nuclei, so long as the latter are young, and, in many, as long as they exist; yet *there occur, although rarely, nuclei in which nucleoli cannot be recognised definitely, or become distinct only at subsequent periods;* and accordingly, the nucleolus cannot, for the present, be *so unconditionally* regarded as an *essential constituent* of the cell as the nucleus. Usually a nucleus contains but one nucleolus; frequently there are two, seldom three, and in very isolated cases four or five are present, which then either lie eccentrically or free in the nucleus.

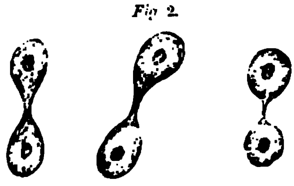
Quite recently, *Donders*, in a very remarkable paper (see infra), has asserted, that all cell-membranes consist of one and the same, or at least of very closely allied, substances, which agree in their properties with the substance of *elastic tissue.* I, for my part, am of opinion, that all animal cell-membranes consist *originally* of the same material, and, indeed, of a *proteine compound;* but that, in consequence of subsequent metamorphoses, differences of composition and reaction may arise. Thus many membranes become, in the course of time, more resistant, and approximate, as *Donders* correctly states, to elastic tissue; others become transformed into gelatiniferous tissues, like those of the formative cells of connective tissue; others, again, into syntonine, as in the smooth muscular fibres, others into horn, etc., etc. If we adopt a proteine compound as the primitive cell-membrane, as we are constrained to do from the reaction of young cells and embryonic parenchymas, there results an agreement with vegetable cells; seeing that in this case the *primordial utricle* of the latter, which consists of a proteine substance, may be regarded as the analogue of the animal cell-membranes; whilst the cellulose membrane appears as a secondary formation, as a product of excretion. This may be the case in the animal tissues of the Tunicata, which are composed of cellulose; in which case, my assertion, that, in the latter, cell-membranes composed of cellulose occur—and that of *Schacht* (*Müll.* Arch. 1851), that they are nitrogenous—would be compatible. If the future justifies this comparison of animal-cells with the primordial utricle of plants, which I do not doubt, all the chemical metamorphoses of the cell-membranes *would,* very probably, *be owing to deposits which are precipitated on their outer side,* similar to the cellulose in plants; so that, besides the original proteine membrane, other secondary elastic membranes, or gelatinous envelopes, etc., would require to be distinguished. In this case we could say, that even [illegible] take place on the ex- [illegible] that the original [illegible] cartilage-cells.

[illegible]—With regard to the formation of cells, [illegible] between the *free origin* of [illegible] *of other cells.* [illegible] presented, the occurrence [illegible] and more doubtful: and it [illegible] as in plants, in dependence [illegible]. In this process of cell-multiplica- [illegible] produce secondary cells, as they [illegible] by division—[illegible] *cell-forma-* [illegible] The cell-nuclei always play a very [illegible] of cells, and appear as the [illegible].

[illegible] plants, regarded the [illegible]—that by the intervention of [illegible] more and more [illegible] animals and plants agree. As for me, [illegible] 1844; *Ann. d. sc. Nat.* 18[illegible] the descendants of the [illegible]; and that even in the [illegible] consisting of cells, as in the [illegible]. Accordingly, I found [illegible] German *Handbook of Histo-* [illegible] very much. Quite recently, *Virchow* (in [illegible] 1854, p. 329), has made known a series of facts, from the department of pathological anatomy, which show that in many places where formerly a free cell-formation was admitted, it does not occur. If to these facts are added the new observations of *Virchow*, with regard to the development of bones, as well as the recent investigations into the formation of the lymph-corpuscles, we may indeed conclude, that a free formation of cells does not anywhere exist.

§ 10. *Multiplication of Cells by Division*, is much more widely distributed than has hitherto been supposed; it being highly probable that the entire growth of the embryonal and fully developed cell-tissues, with the exception of cartilage, is solely effected by division. This process is easily observable in free cells suspended in fluid, as in the red and colourless blood-cells of mammalia, birds, and amphibia. Here, in elongating

Fig. 2.



Blood globules of chick, in the act of division.—Magnified 350 diameters.

cells, there are seen forming, from the original simple nucleus, to all appearance likewise by division, two; then the cells become constricted in the middle, contract more and more around the separated nuclei, and, lastly, break up into two, each of which contains its nucleus. In the embryo-chick the blood-cells are to be seen in all conceivable stages of this process; so that ultimately they are only connected by a thin filament; and not the slightest doubt can prevail concerning the real occurrence of this kind of cell-multiplication.

In other free cells, as those of the juices of glands, the process of division has hitherto been observed only in one place with certainty; viz. in the ova of Mermis albicans, which, according to *Meissner's* discovery (*Zeitschr. f. w. Zool.* v.), become detached as buds from other cells.

In compact cell-tissues, it is much more difficult to demonstrate the processes of cell-division with certainty. I assume this mode of cell-formation to take place wherever, on the one hand, an increase of cells in number has been demonstrated, and where, on the other, every trace of a free cell-formation or of endogenous multiplication is wanting; and, accordingly, in all embryonal cell-tissues, with the exception of cartilage, and in the adult in the entire growth of the horny tissues, and perhaps in many other cells.

With regard to the mode of cell-division in compact tissues, it may be further remarked, that it takes place both in the longitudinal and transverse diameter of the cells: in the former case, they grow in the direction of the surface; in the latter, in that of the thickness.

Schwann was not aware of cell-division. The first who saw such a process in the blood-corpuscles of embryos, was *Remak;* yet he subsequently retracted his statements, to pronounce himself in favour of them again, after I had confirmed and declared them to be correct. In pathological formations, this mode of cell-multiplication has likewise been found by *Günsburg* and *Breuer* (see BREUER, *Meletem. circa Evol. ac formas Cicatricum.* Vratisl, 1843, p. 31). I also refer the *transverse and longitudinal division of the protozoa* to cell-division; since these animals possess the structure of simple cells, and their nucleoid body participates in exactly the same way in the cleavage, as the cell-nucleus does in ordinary cells. *In pathological formations,* cell-division may perhaps be more frequently found, when once attention shall have been directed to it. In the vegetable kingdom cell-division is rare, and only seen in the lower organisms.

§ 11. *The Formation of Cells in others or the Endogenous Origin* of them presents various modifications.

a. In the first form, which I call the *endogenous cell-formation* [illegible] first formed in one cell several [illegible] then the total contents of [illegible] same number of parts as there [illegible] a nucleus: and, lastly, [illegible] around these portions of [illegible] To this category [illegible] the development of the [illegible] in *Müll. Arch.* [illegible] of the yelk, a peculiar [illegible] the first development in [illegible] as an introduction to [illegible] of the embryo, and because [illegible] simple cell, comes under the [illegible] After the primitive nucleus of the ovular cell, the germinal vesicle, has disappeared

[illegible] formation, the granules of the yelk no longer form one compact heap as formerly, but become scattered and fill up the whole ovular cell. Then there arises, as the first sign of the commencing development, a new nucleus in the midst of the yelk around a new nucleus [illegible] This is the first nucleus of the embryo, which, acting as a point of attraction upon the yelk, again unites it to form a spherical heap. In the further progress of development, there are formed from the first nucleus, by endogenous production, two new ones, which, as soon as they have become free by the resolution of the mother-nucleus, separate somewhat from one another, act as new centres upon the yelk granules, and this the primitive heap breaks up into two. The multiplication of nuclei and yelk segments (the former always preceding the latter) then proceeds in a similar manner till a very large number of small segments are present, filling up the whole space of the yelk cells; it is only exceptional that the yelk segments do not break up until the nuclei have multiplied to three or four; so that three or four segments, instead of two, are directly formed from each of them. This process is called the *total cleavage*, because here the entire yelk becomes arranged around the newly formed nuclei; the *partial* cleavage essentially agrees with it, only differing in the circumstance that not all the yelk, but, according to the different animals, a smaller or larger portion of it envelops the newly-formed nuclei. When the process of division has attained a certain stage, all the segments become surrounded with membranes, either simultaneously or in successive layers, and are transformed into true cells; from which circumstance we are warranted in classifying endogenous cell-formation.

b. The phenomena attending the *endogenous formation of cells by division*, which is the usual mode of multiplication in cartilage, are the most complex. Cartilage-cells differ, in my opinion, from the great majority of the cells of the higher animals, in having, like vegetable cells, *two membranes*, an internal delicate proteine membrane, the *primordial utricle*, and an external firm capsule, analogous to the cellulose covering of plants, the latter of which is, as in plants, a *secondary formation*, an excretion of the former. Where cartilage-cells multiply, the first thing observable is a division of the nucleus into two; then the nuclei separate from one another, and a partition, as it were, passes in between them, upon which the mother cell divides into two completely separated spaces, each of which embraces one nucleus and the one-half of the contents of the cell. Subsequently two complete secondary cells generally become distinct within the mother-cell and entirely fill it up, proving that the partition is, properly, double from the commencement. The formation of the partition of the secondary cells is, perhaps, to be understood as being effected in the same manner as in plants: it being assumed that, the primordial utricle becomes constricted and ultimately divides. Now, in cartilage, the above-mentioned process is repeated, as a rule, many times with great regularity, and in such a manner that the secondary cells, after their formation, first secrete external cartilage membranes,—which unite with those of their mother cell, and at the same time form a partition between them,—and then divide anew (Fig. 2). Meanwhile, the cartilage membranes of the mother cells *usually continue to exist* for some time longer, but

Fig. 4.

Cartilage cells of a full-grown Tadpole, semi-diagrammatical figure. 1. A mother cell, whose primordial utricle is in the act of dividing *a*. its thick secondary membrane or cartilage capsule. *b*. Primordial utricle, enclosing the cell contents with the nucleus. *c*. Place where it is constricted (not observed).

2. A Mother cell with two generations. *d*. Outer cell membrane of the mother cell. Outer cell membranes of the cartilage capsules of the secondary mother cells enclosed by them, which, with *f*., form a double partition through the chief mother cell. *g*. *g*. Secondary cells.

subsequently disappear as histologically separated structures, and coalesce with the matrix connecting the cartilage-cells. Yet it occasionally happens, particularly in the costal cartilages, and in pathological articular cartilages, that the mother cells exist for a long time and become filled with many generations of secondary cells, which are either enveloped by the secondary or tertiary mother-cells, or fill up the large capsule as a compact heap.

With regard to the manner in which the nuclei multiply themselves in the different forms of cell-multiplication, this much is certain, that the *nucleoli* always first divide into two and then separate somewhat from each other. In certain cases, a simple division of the nucleus may then follow, whilst in others, they are formed endogenously in pairs in the enlarged mother-nucleus, and become free by the resolution of the latter. In the yelk segments of the ova of frogs, *Remak* found towards the termination of the cleaving process, 2, 3—8 nuclei enveloped by one mother-nucleus-membrane.

§ 12. *Vital Phenomena of fully developed Cells.—Growth.* When cells are once formed, a considerable number of functions appear in them, which, like those of the entire organism, are divisible into *animal* and *vegetative*. The latter relate to the form of the whole cells and of their contents, as well as to their chemical composition, and may be designated by the names of *growth* and *molecular changes*.

With regard to *growth*, it occurs, perhaps, in all cells, although not everywhere in the same degree. It exerts its influence both upon the contents and upon the cell-membranes; but is, perhaps, chiefly dependent, in its peculiarities, upon the latter, in which growth appears in a two-fold manner, inasmuch as they either extend in superficial area or become thickened. The *former kind of growth* is usually omnilateral, and hence cells may become enlarged without change of form, as, for example, ova, many nerve cells, etc., but is frequently unilateral as in all cells which deviate in their form from the primitive spherical shape; and, in this case, the cell-membranes deposit new material and extend only at one or two or several points. *Thickening* of the cell-membranes, with or without increase in superficial area, is to be found in a greater or less degree in almost all cell-membranes, all, perhaps, becoming somewhat firmer with age; yet it is extremely difficult to decide in individual cases, whether such thickening is owing to an increase of the membranes them-

[redacted]

selves or to *deposition* upon the outer surface of the cell-membrane.

The *Nuclei* and *Nucleoli* also participate in the growth of the cells to a certain degree; and the former, more especially, present, together with an omnilateral, an unilateral growth, in consequence of which they become elongated.

§ 13. *Processes taking place in the Interior of Cells.*—In order to obtain a clear insight into the processes going on in the interior of cells, it would be especially necessary to have a more accurate knowledge of the chemical properties of their contents than we now possess. Only two kinds of cells, the ovum and the blood-cells, have been more carefully investigated; but these are so peculiarly conditioned, that they can scarcely serve as types of cells in general. Nevertheless, from their analysis, some conclusion may be drawn as to other cells, and from such analysis combined with what micro-chemical investigation furnishes, we may, perhaps, be warranted in regarding cell-contents in general as a moderately concentrated solution of proteine, with alkaline and earthy salts and dissolved or suspended fat-particles. Many cells, however, differ very considerably from this, which is undoubtedly the ordinary condition of all cells, at least in the young state, in so far as in them some of the above-mentioned constituents preponderate very much, or entirely new substances are superadded. Thus, there are cells with much proteine, as the ganglionic globules; and with much fat, as the fat-cells, the cells of sebaceous glands, and the mammary glands, etc.; further, cells with hæmatine, pigment, constituents of the gall and urine, mucus (epithelial cells), serum (pathological fat-cells, corpuscles of connective tissue, lacunæ of bone), etc.

The phenomena manifested by these so variously constituted contents, during life, may be best designated as — absorption, assimilation, and excretion.

These are chiefly owing to chemical and physical causes, and may for the most part even be followed with the microscope, seeing that changes in the form and contents of the cell very frequently go hand-in-hand with them. With regard to absorption, it presents itself in all cells, and the primary cause of the entrance of material is simply to be sought in the capability of imbibition of the cell-membrane and contents. This imbibition is, however, not to be understood as if the cells admitted indiscriminately all substances approaching them; on the contrary, they present, according to time and place, quite definite relations to the cytoblastema, rejecting one constituent of it and taking up another; and the same thing occurs with the absorptive power of those cells which possess contents from the first moment of their formation. That this is really the case, is, for example, proved by the circumstance, that in embryos, notwithstanding the uniform formative material, *i.e.* the blood-plasma, for all the cells, some take up more of these, others more of those materials, and from this results still more distinctly that the contents of probably all cells are chemically different from the cytoblastema by which they are formed and maintained, as has recently been more clearly demonstrated in ova and blood-corpuscles, the latter, for example, containing much more potass than the blood. The reason of this phenomenon may be thus stated in general terms, that the cell-membranes do not act like simple filters, but allow one substance or another to permeate them, according to their chemical composition, the nature of the surrounding fluid, their condition of aggregation, and their thickness. True *endosmosis*, which has frequently been assumed as occurring in the cells, does not, according to my observations, appear to occur, in as much as the cells in their totality rather present the condition of simple bodies saturated with fluid.

The substances composing and taken up by the cells, undergo manifold metamorphoses, in consequence of the vital process. These *metabolic phenomena* (*Schwann*) are referable, firstly to the *cell-membrane*, and secondly, to the *cell-contents*. With regard to the former, this much is certain, that the membranes of most cells not only become thicker and firmer with age, but also assume other chemical properties; yet it is impossible in the individual case to say to what the change is due. In the horny structures, the membranes of the young cells are readily soluble in alkalies and acid, whilst subsequently they resist it in part very much; the same thing is found in the higher elementary parts, as the nerve-tubes, animal muscular fibres, and the capillaries, in which the sarcolemma, the sheath of the nerve-tubes, and the capillary membrane, which have the signification of metamorphosised cell-membranes, re-act quite differently from the primitive formative cells. In the cartilage-cells also the membranes become more resistent with age, and the same occurs with the cell-membranes of the ova of many animals, as is best shown in fishes. These examples, which might be multiplied, may suffice to establish the occurrence of metamorphoses of the cell-membranes; subsequent investigation will have to show upon what these depend, whether, as it would appear, the original cell-membrane, in many places, really changes in its composition after a time, or whether, perhaps, the change in the reaction only appears to be founded in the absorption of foreign substances, *in the incrustation of the cell-membrane with salts*, etc., or whether, as is most probably the case in cartilage-cells, it is dependent upon *secondary depositions on the exterior of the primitive membranes.*

The metamorphoses in the *cell-contents* are of two kinds, *formative* and *resolvent*. Both processes can be readily followed in the embryos of different animals, in which, firstly, the primitive cells, distended at the beginning with the elements of the yelk, gradually acquire more fluid and homogeneous contents, the yelk granules resolving sometimes from the cell-membrane towards the nucleus, sometimes from within outwards; and secondly, in the cells so changed, the most various new formations appear, among which those of hæmatine, the different pigments, and of fat, are most conspicuous. But even in adults, metamorphoses of the cell-contents are common, and, at the same time, very important phenomena, occasioning in many places, owing to the enormous number of cells, unexpectedly extensive results; the secretion of the bile may be characterised as the most important of these, which, so to speak, is effected by the activity of the many millions of hepatic cells forming the liver.

A beautiful series of changes may also be traced in fat-cells, which, according to the deficiency or excess of nutritive fluid, lose, in the former case, their contents, and may eventually contain only serum, in the latter become distended with fat-drops; further, in the cells of glands secreting fat, which, at first poor in fat, are ultimately quite distended with it, as also in the lymph-corpuscles, which develop the colouring matter of the blood in themselves, and become blood-corpuscles; lastly, in the ova of all animals which deposit fat and proteine within themselves. The formation of mucus also must, according to my observations, be considered as taking place in the epithelial cells of the mucous glands and membranes, as also that of pepsine, as it is called, in the cells of the tubular glands of the stomach. *Comparative Anatomy* can furnish further proofs of the most diverse description; and I now only mention here the formation of uric acid concretions in the renal cells of Mollusca, that of sepia in the cells of the ink-bag of the Cephalopoda, of crystals and concretions of various kinds in cells of invertebrata and of special colouring matters in those of the *Mollusca*. Very interesting also is the occurrence, *in invertebrate* animals, of glands consisting of a single cell, as shown by *H. Mohl* and others. In the department of pathological anatomy there belong to this category, the formations of pigment, the metamorphoses of the cells containing blood-corpuscles, the depositions of fat in cells of all kinds, etc.

Manifold [illegible] go hand in hand with these changes, such as the above-mentioned thickenings and laminated depositions upon the inner side of the cell-membranes; further precipitations in the cell-contents of granules of divers kinds, as of pigment, albuminous substances (many epithelial cells, hepatic cells, etc.), the formation of fat-drops, elementary vesicles, concretions, crystals and nuclei. Even *movements*, similar to the cyclosis of plants, appear to occur in cells of the lower animals (seen by me in cells of Polycelinum stellatum? and in Protozoa (currents in Loxodes bursaria, contractile vesicles in different genera); whilst on the other hand, the *Brownian molecular movement*, i.e. a more or less active tremulous motion of granules without any further *change of locality*, which is perceptible in many cells under the microscope most distinctly in the pigment-cells of the eye) can scarcely be reckoned among the phenomena occurring during life.

§ 14. *Excretive Processes.*—The vegetative functions of animal cells are not merely confined to the taking up and transformation of matters, but materials are again set free, which are either further employed in some way, or are simply removed from the organism. In many cases, this takes place by the dissolution of the cells, as in many glands in which the mature secretion (milk, semen, cutaneous sebaceous matter, bile of the lower animals, ink of the *Cephalopoda*) consists, so to speak, of nothing else than the contents of the gland-cells. In other instances, the cells remain unaltered while they secrete substances externally, and thus the process presents itself in a two-fold manner.

1. *Cells may give off materials which they had taken up from without unaltered.* This is the case with the epithelial cells of the glands, which, like the kidneys, lachrymal glands, lungs, etc., simply allow substances to pass out of the blood, as also with the cells lining the surfaces of the serous membranes and of the external skin, and probably many others.

2. *Cells may separate substances which they have prepared within themselves.* Thus, the fat-cells give off fat in emaciating individuals; the cells of the liver, bile; those of the gastric glands, pepsine; those of the mucous membranes and glands, mucus. To this category also belong the secondary cell-membranes or the cartilage-capsules, lying external to the primitive cartilage cells, as

also the *membranæ propriæ* of many glands, which appear as products of the glandular cells, the thickenings on the epithelial cells of the small intestine, and the cuticular productions of lower animals. These excretions of materials are the consequence of the pressure to which the cell-contents are exposed, which pressure is, on the one hand, referable to the pressure of the blood, and on the other, to the attraction exerted by the cells themselves during the absorption of materials, and to the elastic forces of the cell-membranes. Many cells are also simply *washed out* by the fluid constituents of the secretion.

The separated materials frequently present no further relations to the cells whence they come, and are either subservient to special purposes, or are entirely removed, as in the glands. In some places, assuming a solid form, they remain external to the cells as extra-cellular substance, and either form external envelopes around the individual cells, corresponding to the cellulose membrane of plants, or larger coverings of entire cell-groups, as the *membranæ propriæ* of glands (*e.g.* of the *tubuli uriniferi*), the proper sheath of the *chorda dorsalis*, and probably also the vitreous membranes of the eye (capsule of the lens, *membrana Demoursii*), or, lastly, peculiar masses attached on one side to the cells, as in the enamel of the teeth (see below, in the section on the teeth), the cylindrical epithelium of the small intestine, and the cuticulæ of lower animals. Very rarely the substances separated by cells unite to form a *firm intermediate* layer or *intercellular substance* connecting them, as in the matrix of the dentine (see the teeth), and in the cellulose coverings of many *tunicata*. The matrix of cartilage also belongs, in part at least, to this category, in as much as it consists of the outer coalesced cell-membranes of the cartilage-cells. In other cartilages, there is superadded to these, a special intermediate substance, which appears to be directly deposited from the blood of the perichondrial vessels. In other tissues, we find a firm, gelatiniform, or fluid intermediate substance, frequently in large quantity, as in the embryonal vitreous body, embryonal loose areolar tissue, in the follicles of the vascular glands, in the blood and chyle, and in all parts formed by areolar tissue; but this substance is not, perhaps, due, for the greater part, to the cells, or to histological elements arising from them, and does not, in consequence, belong to this category.

Intercellular Spaces formed between the cells by their excretions, have not yet been satisfactorily demonstrated in animals; yet most of *the glandular spaces*, and the cavities of the heart and larger vessels, perhaps belong to this category, in so far as they appear to arise from the secretion of fluid in the interior of primitively compact cell-masses.

The application of the doctrine of the double cell-membrane in vegetable cells, the primordial utricle (*Mohl*) and cellulose membrane, to animal-cells, took place in 1852, contemporaneously and independently, by *Remak* (MÜLL. *Arch.* 1852, p. 63, *seq.*) and myself (*Handb. d. Geweb.* 1852, pp. 14, 29). Since this time, my observations on the cuticular structures (*Transact. of the Phys. Med. Soc. of Würzburg*, viii.) have shown that secondary depositions from the cells, analogous to the cellulose membrane of vegetable-cells, are to be found in a great many places, and are often characterised by a very particular structure, especially by the existence of a large number of extremely fine pores, pervading them in the direction of their thickness.

§ 15. *Animal Functions of Cells.*—To the vital phenomena of cells, also belong certain movements which appear in cells, of which it is extremely difficult to say whether they concern only the contents, or the cell-membranes also. They are most simple in those lower animals which have the signification of simple cells. Here there exists an entire group, *Rhizopoda* (*Amœba*, *Arcella*, *Difflugia*, etc.), the substance of whose bodies, without presenting a differentiation between envelope and contents, is capable of assuming the most diverse shapes. A similar amorphous "*contractile substance*" (*Ecker*), which also may be designated *Sarcode* (*Dujardin*), also occurs in the *Protozoa* provided with a special outer membrane (cell-membrane), and here occasions the changes of the contractile spaces, the movements of the pedicle of the *Vorticellæ*, and probably also the currents of the fluids, such as are found in *Loxodes bursaria*. In these animals, the outer envelope also appears to be contractile, either in its totality, or in its external processes, the cilia; yet it is also conceivable that all the movements are only dependent upon the contents, and that the envelope simply follows them as an elastic body. On this view, a cilium must be conceived as being a pedicle of a vorticella in miniature; in which latter, as *Czermák* shewed, the inner filament connected with the substance of the body is contractile, while the envelope is elastic.

In *the higher Animals*, contractile phenomena of this kind are found, firstly, in individual cells; and then in parts of tissues which owe their origin to a metamorphosis of single cells. To the former belong, 1. *Cilia*, external processes of cells, outgrowths which probably are not only to be regarded as prolongations of cell-membranes, but also of the contents; so that it cannot be , whether their power of contraction is to be referred to the cell-contents, or to the membrane, or to both. 2. *Contractile Fibre-Cells*, in which the original cell, with the membrane and contents, appears to have become converted into a soft, contractile fibre; a merely elastic envelope has not yet, at least, been demonstrated with certainty. 3. *Cells composing the Hearts of certain Embryos* (*Alytes*, *Sepia*, *Limax*, *Gallus*), which, before they have become converted into muscular fibres, accomplish contractile movements. The energetic phenomena of contraction, which *v. Siebold* has observed (compare my figure in *Wiegm. Arch.* xiii. pt. i.) in the cells composing the young planarian embryos, are generally reckoned under this head. Similar movements seem, according to the more recent observations of many authors, to occur in other cells; as, for instance, in the *colourless blood-corpuscles* (*Wharton Jones*, *Robin*, *Ecker*, *Lieberkühn*, *Kölliker*); in the *segments* of the fecundated yelk of the frog (*Ecker*); in the *cells* of *Spongilla* (*Lieberkühn*); in the pigment-cells of *Batrachia* and of *Chamæleo* (*Brücke*, *Virchow*, *Wittich*, *Busch*, *J. Lister*); in the corpuscles of the connective tissue of lower animals (*Huxley*, *Busk*, *Kölliker*); in the yelk of the eggs of fishes (*Ransom*, *Reichert*), etc., etc. In some of these cells, the formation of real processes, or prolongations of the membrane and contents, can easily be shown; but in other instances, as in the yelk of eggs of fishes, and, according to *J. Lister's* observations, even in the pigment-cells of frogs, the phenomenon consists only in a movement of the granules of the cell-contents, without any changes in form of the cells themselves.

Among the phenomena of contraction which appear in cells, I reckon, also, those of animal muscular fibres, which, as *Remak* and I have shown, are nothing else than enormously-developed single cells, with many nuclei; which cells, in some cases also (insects, hearts of mammalia), coalesce, so as to form a network. In fully-formed, transversely-striped muscular fibres, it is certain that it is not the envelope representing the cell-membrane, the *sarcolemma*, but the cell-contents, the *fibrillæ*, which are contractile; and thus it becomes probable that all contractile fibres of higher and lower animals are similarly conditioned. In the *chromatophora* of *Cephalopods*, and of some *Pteropods*, the change of form does not depend upon the cells themselves, but upon muscular fibres attached externally to them (*Kölliker*, *Harless*, *H. Müller*).

In a still higher degree than the motory phenomena of animal-cells, which within certain limits also occur in plants (cilia of spores, contractile spaces in Volvox, *Busk*), the very peculiar processes which we cannot but consider as taking place in the nerve-cells, deserve the name of animal functions, since these processes are nothing else than what the physiologist understands as the functions of the gray nervous substance. We cannot, of course, enter into discussion of them here; and the more so since these functions are completely inaccessible to microscopical observation.

Donders was the first to assert the opinion, that only the contents of cells and not the cell-membranes are contractile; and, I must confess, that the longer I consider the subject, the more the idea of *Donders* pleases me; yet it appears to me as still rather premature, in entirely denying the power of contraction to cell-membranes, there being nothing *à priori* to adduce against this view, while a decision, founded on fact, cannot as yet be formed in many cases.

§ 16. *Metamorphoses of Cells.—Different Kinds of Cells.*—The destination of the cells which occur at earlier or later periods in the organism is very various. A very considerable number of them remain for only a short period in their original state, and, subsequently, unite with others for the formation of the higher elementary parts. Others, again, do not indeed enter into any such connections, but change more or less their former nature, as the horny plates of the epidermis and nails. Many cells, lastly, never go through any metamorphoses, but remain as cells, till they perish, sooner or later, often not till the destruction of the organism itself, such as epithelium-cells, the cells of glandular parenchymas, those of the nervous system, etc.

Permanent Cells may be arranged most conveniently under the following heads:—

1. *True Cells*, which have not altered their cellular nature in any essential point, occur in the epidermis (*stratum Malpighii*) epithelia, in the blood, the chyle, the lymph in gland-juices, adipose tissue, gray nervous substance, the red medulla of bone, in glands (liver, spleen, supra-renal capsules, closed glandular follicles) and in cartilages. These cells may be divided *according to their form*, into round, disc-shaped, cylindrical, conical, ciliated, and stellated: according to their *contents*, into cells containing fat, proteine, serum, haematine, biline, pepsine, mucus, and pigment: and, with regard to their *occurrence*, some are isolated either in *fluids* or *solid* tissues, while others are united to form *simple cellular parenchymas*; others, lastly, being connected by an intercellular substance of some kind.

2. *Metamorphosed Cells*, which have altered their original structure more or less. To this category belong—

a. Horny Plates, flattened *polygonal* or *fusiform Cells*, the membranes of which have blended with the contents; in the epidermis, the laminated pavement epithelia, the nails and hairs.

b. Contractile Fibre-cells; fusiform, slightly flattened, considerably elongated cells, the membranes of which, together with their pulpy contents, have become transformed into a contractile substance, in the smooth muscular fibres.

c. Striated Muscular Fibres; long fibres with many nuclei, with a distinct envelope, and a contractile, often fibrillated, interior substance, originating from the excessive growth of single cells.

d. Fibres of the Lens; very elongated cells, with viscid, more or less firm contents, rich in albumen.

B.—HIGHER ELEMENTARY PARTS.

§ 17. The higher elementary parts correspond genetically to an entire sum of simple ones; and, indeed, as far as we yet know, it is only the cells which are capable of producing them. The manner in which this happens is various. That is to say, the cells, while they coalesce, either retain their cell-nature, and in part also their independence; and then there arise, according as they are fusiform or stellate cells, *cell-fibres and cell-networks; or the cells entirely lose their independence on union*; and, in this case, according as the cells are arranged in linear series, or are wholly connected with each other *on all sides*, form elongated, elementary parts, networks and membranes, the two former of which again, according to the kind of metamorphoses of the contents of the united cells, may appear as *fibres, bundles of fibrillæ, tubes, fibrous networks, and as plexuses of tubes*. As these elementary parts will be spoken of more in detail below, in treating of the tissues, a short enumeration of them here may suffice.

They are: 1. *Higher Elementary Parts, which present, more or less distinctly, the Cells composing them.*

1. *Cell-networks from the tissue of connective substances.* To this category belong the corpuscles of connective tissue (*Virchow*), the cartilage-cells of certain *plagiostomatous* fish (*Leydig*), all anastomosing pigment-cells, the *lacunæ* of bone and the dental tubes, the cells of the fat-body of the *Lepidoptera* (H. MEYER, *Zeitschr. f. w. Zool.* i. p. 178).

2. *Cell-networks of Muscular Tissue.* Anastomosing, smooth, or transversely striped cells of the heart and skin of the lower animals.

3. *Cell-networks from Nervous Tissue.* Anastomosing nerve-cells of the retina and of the central organs.

2. *Higher Elementary Parts—the Formative Cells of which are no longer recognisable.*

1. *Fibres, Fibrous Networks, and Membranes of Elastic and Areolar Tissue.*

2. *Fibrous Networks of the Transversely-striped Muscles.*

3. *Fibres and Fibrous Networks of the Nervous Tissue.*

4. *Tubes and Plexuses of the Blood and Lymph Capillaries.*

5. *Terminations of the Tracheæ of Insects.*

All these higher elementary parts possess essentially the same properties as cells, especially *growth in length, and thickness, absorption, metamorphoses, and excretion of materials*, and, in part, *contractility*, as also other functions, which, perhaps, can likewise be demonstrated in cells. Growth manifests itself very distinctly in the circumstance, that all the above-mentioned elements immediately after their formation are invariably much shorter and narrower than at a subsequent period; the absorption of material is proved by the dependence of their functions upon the circulation, by the phenomena of absorption in the capillaries of the lymphatics and blood-vessels, and by the above-mentioned growth, which can only be conceived as taking place by the absorption of materials into the interior of these parts. A metamorphosis and excretion of materials may also be assumed along with these, as the well-known peculiar products of decomposition in the muscles, the changes of the muscular fibres and the nerve-tubes in altered nutrition and activity, as also the capillaries which are continually giving off the plasma of the blood, sufficiently testify. The muscular fibrillæ possess contractility; and the processes in the nerve-tubes, which, although they possess their analogies in part in the functions of the nerve-cells, are very peculiar, and, for the present, not to be more definitely characterized.

Literature of the Elementary Parts.—Besides *Schwann's* work, cited above, we may mention KÖLLIKER, *Die Lehre von der thierischen Zelle, in* SCHLEIDEN *und* NÄGELI'S *Zeitschrift für wissenschaftl. Botanik.* Part II. 1845. *Entwicklungsgeschichte der Cephalopoden*, 1844; and a Paper on Cuticular Structures and Pores in Cell-membranes, in *Transact. of the Würzb. Soc.* Vol. viii. REMAK. *Ueber extracelluläre Entstehung thier. Zellen und die Vermehrung derselben durch Theilung, und über Entstch. des Bindegewebes, u. d. Knorpel*, in MÜLL. *Arch.* 1852. i.; as also the treatise of DONDERS, cited under Elastic Tissue; and the Embryological Monographs of REICHERT, BISCHOFF, VOGT, REMAK, and myself. Besides, compare the more recent comparative histological treatises of *H. Meckel, Leydig, Leuckart, Carpenter, Huxley, Gegenbaur, Meissner*, myself, and others.

[redacted]

II. OF TISSUES, ORGANS, AND SYSTEMS.

§ 18. The elementary parts of the simple and higher kinds are not scattered without order in the body, but united according to definite laws to the tissues and organs, as they are called. Under the former name is designated *every constant grouping of the elementary parts always recurring in the same way in analogous parts;* under that of an organ, on the other hand, is understood *a certain sum of elementary parts possessing a definite form and function.* When several or many organs of similar or different kinds unite to form a higher unity, the latter is called *a system.*

It is difficult to classify the tissues properly. When we only consider the conditions, such as they are, found in the adult organism, it is easy, indeed, to enumerate a gradually ascending series of simple to more and more complex formations. But in this way, formations which are closely related to each other would be torn asunder, and conversely. Better results are attainable, when, together with the fully developed form, we also take the origin and the chemical and physiological conditions into account, and from this point of view the following series of tissues may be constructed:—

1. CELL-TISSUES.
   Epidermic tissue. Tissue of true glands.
2. TISSUES OF CONNECTIVE SUBSTANCE.
   Mucous tissue. Elastic tissue.
   Cartilage-tissue. Areolar tissue.
   Osseous tissue and Dentine.
3. MUSCULAR TISSUES.
   Tissue of the smooth muscles.
   Tissue of the transversely striped muscles.
4. NERVE-TISSUE.
5. PARENCHYMATOUS TISSUES OF VASCULAR GLANDS.

The organs may be divided into simple and compound.

1. SIMPLE ORGANS.
   1. Epidermis, epithelia, hairs, nails, enamel, lens.
   2. Simple true glands.
   3. Vitreous body.
   4. Chorda dorsalis, true cartilage, and elastic cartilage.
   5. Elastic *ligaments and* membranes.

6. Tendons, ligaments, fibrous membranes, fibro-cartilage.
7. Bones and teeth.
8. Smooth muscles and muscular membranes.
9. Transversely striped muscles and muscular membranes.
10. Nerves and ganglia.
11. Simple glandular follicles.

2. COMPOUND ORGANS.

12. Vessels.
13. Vascular membranes (external skin, mucous and serous membranes, proper vascular coats).
14. Special organs of the intestinal canal.
15. Compound true glands, with their individual sections.
16. Compound vascular glands (spleen, tonsils, supra-renal capsules).
17. Central organs of the nervous system.
18. Higher organs of the senses.

The organs lastly unite to form *special systems*, of which the following may be distinguished:—

1. *The System of the External Skin*, consisting of the corium, epidermis, the horny structures, and the larger (mammary glands) and smaller glands of the skin.

2. *The Osseous System*, comprehending the bones, cartilages, ligaments, and articular capsules.

3. *The Muscular System*, viz: the muscles of the trunk and extremities, the tendons, fasciæ, tendinous ligaments and bursæ mucosæ.

4. *The Nervous System*, consisting of the large and small central organs, the nerves and higher organs of the senses.

5. *The Vascular System*, consisting of the heart, the blood and lymph vessels, as well as the lymphatic glands.

6. *The Visceral System*, comprising the intestinal canal, the organs of respiration, with the thymus and thyroid, the salivary glands, the liver and spleen.

7. *The Urinary and Sexual Systems.*

Since the individual organs and systems will be spoken of in detail in the special part, we do not require to enter here into a more minute description of them; and it accordingly only remains to characterise the tissues themselves somewhat more minutely, while, at the same time, a few general remarks concerning the organs may be most fitly annexed.

1. Cell-Tissues.

§ 19. The epidermic and the glandular tissues, which I include under the cell-tissues, have this in common, that they both, with but few exceptions, arise from the continuous layer of cells lining the inner and outer surfaces of the embryonal body; and even in the fully developed condition, essentially consist of cells, which, in the one case, appear in compact masses, but in the other, generally enclose spaces. In both tissues homogeneous structureless membranes are more or less extensively present. These are to be regarded as products of excretion from the cells; in the glands, they surround the glandular elements as *membranæ propriæ*, whilst in the epidermic tissue they are spread out in form of a layer between the cells and subjacent vascular parts, with which they are often intimately blended. Both tissues very closely agree in respect of the form and chemical composition of their cells; and the close relationship between them is even more decidedly indicated by physiological considerations, seeing that at least the main function of glands, excretion, also belongs to very many epidermic tissues. The latter also participate, it is true, in the process of absorption, which can be ascribed to but a small number of glands, and present other and altogether special relations; circumstances which, however, do not affect the affinity of these two tissues.

§ 20. *Epidermic Tissue.*—The *morphological* character of epidermic tissue consists in its being entirely made up of independent, generally nucleated cells, intimately connected, without any visible intermediate substance, which in part retain their perfect vesicular character, and in part are converted into solid scales and fibres. In a chemical point of view, this tissue is still but little known, yet this much has been made out, that the cells principally contain an albuminoid substance, partly, also, mucus; and that, at first, all possess readily soluble protein-membranes, which, however, subsequently become partly transformed into a substance which resists, more or less, the action of acids and alkalies, and is named horn-substance, or *keratin*. With the exception of the lens and the enamel of the teeth, which are destined for altogether special ends, the physiological purpose of the epidermic tissue is chiefly to serve as a protective covering to parts rich in vessels and nerves, and by the activity of its elements, to take part in the processes of secretion and absorption. All epidermic structures are non-vascular, and are maintained by a plasma passing into them from the subjacent vessels. In most cases, when the older parts of their tissue wear away, it is renewed with extreme facility by the formation of new elements in the deeper layers; and even after complete destruction, they are readily reproduced. The epidermic tissue appears in the following forms:—

Fig. 5.

Scales of the horny layer of the human epidermis, magnified 350 times. 1, 2, 3, from the arm; 2 and 3, treated with water; 4, from the glans penis, with a nucleus.

A. As *proper epidermic tissue.* To this division belong—

1. *Horny tissue.*—This always consists of compact masses of cells, which are soft in the neighbourhood of the vascular matrix, but when further removed from it, become more firm and hard (cornified), and often lose their original cellular character and their nuclei, and become cemented into horny plates. To this division belong the following organs:—

a. The *Epidermis*, or *Scarf-skin*, which covers the outer surface of the body, and, at the large openings of the internal cavities, is continued into their epithelial lining.—It consists of two rather distinctly defined layers, the *mucous layer*, with soft, roundish, polygonal, sometimes coloured cells, which adapts itself accurately to all the inequalities of the subjacent corium (which nourishes the epidermis), and passes externally into the polygonal plates of the *horny layer* (fig. 5).

b. The Nails.—These may be regarded as a modified part of the epidermis, the horny layer of which has attained a still greater degree of firmness, and lies together with the *mucous layer* upon a special depressed surface of the corium — the bed of the nail — and is, in part, lodged on a special groove — the fold of the nail.

c. The Hairs.—Filiform epidermic structures, seated upon a vascular papilla, in a special sac — the hair follicle — derived from the corium, and lined by a continuation of the epidermis. The elements in the immediate neighbourhood of this papilla are soft and vesicular, whilst those farther removed from it are transformed in three ways, viz., into plates, flat fibres, and rounded polyhedral cells.

2. As *Epithelium.*—With soft (never cornified) nucleated cells, which have a roundish, polygonal, fusiform, cylindrical or conical figure, and are sometimes ciliated, sometimes not; and which are arranged in one of several layers, whence arise the following varieties:—

a. Epithelium of one layer.

1. *With roundish, polygonal cells* (simple pavement-epithelium, or simple tesselated epithelium). This is found lining the true serous membranes, most of the synovial membranes, the ventricles of the brain (ependyma), the membrane of *Demours*, the anterior surface of the iris, also on the inner surface of the choroid, as far as the *ora serrata* (pigment layer), the inside of the anterior half of the capsule of the lens, the periosteum of the internal ear, the inner surface of the *tubuli membranacei* and *sacculi* of the latter, the inner surface of the endocardium and veins, of many glandular vesicles and canals (racemose glands, kidneys, sudoriferous glands, ceruminous glands, lungs), and the interlobular ducts of the liver (fig. 11).

Fig. 6.

Epithelial cells from vessels; the longer ones from arteries; the shorter from veins.

2. *With fusiform cells*, arranged collaterally in the same surface (fusiform epithelium). Epithelium of arteries, and of many veins (fig. 6).

3. *With cylindrical cells* (cylindrical epithelium, columnar epithelium). This form is found in the alimentary canal, from the cardia to the anus, in the Lieberkühnian follicles, the excretory ducts of the gastric glands, in all other glands opening into the intestine, as well as in the mammary and lachrymal glands; further, in the male urethra, the *vas deferens*, the seminal vesicles, the excretory ducts of the prostate, in Cowper's, Bartholine's, and the uterine glands (fig. 7).

4. *With cylindrical or conical ciliated cells* (ciliated, simple cylindrical epithelium).

Epithelium of the finest bronchia, of the accessory cavities of the nose, of the inner side of the *membrana tympani*, of the Eustachian tube *and*

Fig. 7.

Epithelium of the intestinal villi of the rabbit, magnified 300 times.

uterus, from the middle of the cervix inwards; of the Fallopian tubes, as far as the outer surface of the fimbriæ (fig. 8).

Fig. 8.

Ciliated cells from the finer bronchi, magnified 350 times.

5. *With roundish ciliated cells* (ciliated simple pavement epithelium). Epithelium of the cerebral ventricles.

b. Epithelium of several layers.

1. *With cylindrical or roundish cells in the deep layer, and polygonal, more or less flattened cells*, towards the surface (stratified pavement-epithelium).

Fig. 9.

A simple papilla, with several vessels of epithelium, from the gums of a child; magnified 250 times.

Epithelium of the oral cavity, the lower half of the pharynx, the œsophagus, the lacrymal canal, the conjunctiva of the eye, the tympanic cavity, the vagina and female urethra, the urinary bladder, ureter, pelvis of the kidney, and certain synovial membranes, the pigment of the posterior surface of the iris and of the *corona ciliaris* (fig. 9).

2. *With roundish cells in the deep portion, elongated in the middle, and ciliated, conical, superficially* (ciliated stratified epithelium). Fig. 10.

Epithelium of the larynx, trachea, and larger bronchi, of the nasal cavities, the floor excepted, of the lacrymal sac and ducts, and of the upper half of the pharynx.

Fig. 10.

A.

Ciliated epithelium, from the human trachea; magnified 350 times. *a*. Innermost part of the elastic longitudinal fibres. *b*. Homogeneous innermost layer of the mucous membrane. *c*. Deepest round cells. *d*. Middle elongated. *e*. Superficial, bearing cilia.

3. *As in 2, except that the upper cells are not ciliated.*

Epithelium of the olfactory region.

As an epidermic structure, we may, moreover, designate the *enamel* of the teeth, which contains prismatic, firmly calcified, long fibres, produced by the intervention of the epithelial cells of the enamel organ; probably, however, not by the direct calcification of these cells, but the excretion from them. (See below.)

B. As *Tissue of the Lens.*

The lens, as its development shows, is an epidermic structure; and its long, partly tubular, partly solid fibres, are each developed by the elongation of a single epithelial cell of the capsule. Nevertheless, it deserves a distinct place, partly on account of its chemical composition, and partly on account of the peculiar form of its elements.

Literature.—PURKINJE et VALENTIN, *De Phænomeno generali et fundamentali Motûs Vibratorii continui.* Vratisl. 1833. (Discovery of ciliary motion in the higher animals.) SHARPEY, Art. *Cilia*, in *Cyclop. of Anatomy.* HENLE, *Symbolæ ad Anatom. vill. int.*, Berol. 1837. On the Distribution of Epithelia in the Human Body, Berlin, 1838; and On the Formation of Mucus and Pus, and its Relation to the Epidermis (first accurate description of the different epidermic cells). VALENTIN, Art. *Flimmer-Bewegung* (Ciliary Movement), in *Handwor. d. Physiol.*, *Jäsche de Telis epithelialibus in specie et de iis Vasorum in genere.* Dorp. 1847.

§ 21. *Tissue of Glands.*—The glands possess, as their most essential part, the *secerning elements*, which appear as cellular masses, shut and open vesicles, and tubes, and contain, as the most important constituent, the gland-cells, or gland-parenchym-cells, as they are called. These cells are mostly polygonal or cylindrical, and completely resemble certain epithelial cells; on the other hand, they are very frequently characterised by peculiar contents. The union of these cells, to form the secerning parts of glands, takes place either directly or with the co-operation of homogenous membranes, secreted by the gland-cells (*membranæ propriæ*, as they are called), and of connective tissue. There thus arise, according to the different glands, different secerning glandular elements, which are surrounded by vessels and nerves, and connected together by areolar tissue, with which elastic fibres, fat-cells, and even muscular fibres are intermingled, to form the larger and smaller divisions of the glands. The chief forms of secerning glandular elements in man are the following:—

1. *Solid cell-networks, without rudiments of an investing membrane.* In the liver.

2. *Shut vesicles, with a fibrous coat and an epithelium.* Graafian vesicles of the ovaries; follicles of the thyroid. The thymus, which consists of a common cavity beset with numerous vesicles, perhaps belongs to this division (Fig. 11).

3. *Open, roundish, or elongated glandular vesicles, with a membrana propria and an epithelium.* In the racemose glands (fig. 12).

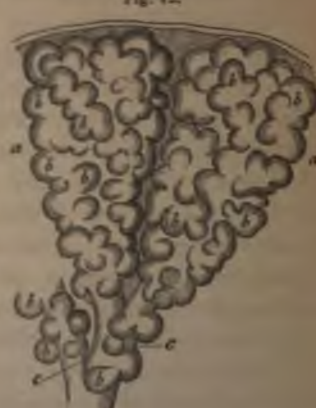
Fig. 11.

Some vesicles from the thyroid of a child; magnified 250 times. a. Connecting tissue between them. b. Membrane of the vesicles. c. Epithelium of the same.

4. *Open glandular tubes, with a membrana propria, or a fibrous coat and an epithelium.* Tubular glands (fig. 13).

To these elements (except in the glands mentioned under 2, which discharge their contents by the occasional bursting of their follicles, or simply allow them to transude, and the most simple tubular glands) are superadded *special excretory ducts*, which, often variously ramifying, either pass directly into the glandular vesicles and tubes, or, as in the liver, gradually transform themselves into the secerning cell network. These ducts at first very much resemble the secerning parts in structure, but always possess epithelial cells which are destitute of the specific contents of the proper gland-cells, and generally present a different form from the latter. Thick excretory ducts consist of a fibrous coat and an epithelium, often, also, of a muscular layer. And, towards their termination, a fibrous, muscular, and a mucous coat very frequently appear as special structures.

Fig. 12.



Two smallest pulmonary lobules. a a. With the air-cells (b b), and the finest bronchial twigs (c c), on which, likewise, other air-cells are seated. From a newly-born child; magnified twenty-five times. Semi-diagrammatical.

But little is yet known concerning the chemical constitution of glands. The gland-cells, as the most important structures, agree, in this respect, also, with the epithelial structures, except that they frequently contain special matters in their interior, such as fat, the constituent of the bile, urine, gastric juice, mucus, etc., and by this means acquire a specific character.

The glands either separate certain constituents from the blood, or prepare, by means of it, peculiar substances, or morphological elements; and the importance of their individual parts is different according to circumstances. In the former case, the gland-cells play rather a subordinate part, and are of importance only in so far as they hinder the passage of some constituents of the blood, and allow certain others to pass through (kidneys, lacrymal glands, small sudoriferous glands, lungs); in the second case, on the other hand, the cells play an essential part in the formation of the secreted juice, as they produce the specific secretion within themselves, which either transudes from them (liver, thyroid, mucous glands, gastric glands, prostate, Cowper's glands, salivary glands, pancreas), or escapes by detachment and gradual destruction of the cells (mammary and sebaceous glands, testicles, large sudoriferous and ceruminous glands). In the latter case, new elements constantly supply the place of the mature decaying gland-cells, by which means the character of these cells, as a lining of the gland canal, is frequently effaced, and they appear as the secretion (testicles, mammary gland during lactation). All the glands mentioned, with the exception of the sexual glands, are developed from the internal and external epithelial formation of the body, with the co-operation of the vascular membranes supporting these epithelia. Some of them appear from the commencement as outgrowths of the membranes mentioned, and retain their cavities during the whole course of their development (lungs, small intestinal glands). Others are at first hollow, but subsequently have solid extensions, by means of which they are further formed (liver); others, again, are solid from the commencement, continue to grow in this condition, and then first acquire their cavities (glands of the skin, racemose glands). The thyroid and thymus also arise, according to *Remak*, as constrictions from the intestinal epithelium. Molecular change is carried on with great energy in glands, and they belong to the most vascular organs of the body. Glandular tissue, except in the uterine glands, is never regenerated; while, on the other hand, hypertrophies of it, and even accidental formations of small glands, occur.

Fig. 13.

Lieberkühnian gland of the pig; magnified sixty times. *a.* Membrana *propria* and epithelium. *b.* Cavity.

The true glands of the human body may, according to the form of the ultimate elements, be classified under the following divisions:—

1. *Glands with shut vesicles,* which burst occasionally, or remain constantly shut. Ovaries, thyroid.

2. *Glands whose parenchyma consists of reticulated cells.* Liver.

3. *Racemose glands,* in which collections of roundish or elongated vesicles are seated upon the ultimate terminations of the excretory ducts.

a. Simple, with one or some few lobules. Mucous glandules, sebaceous glands, Meibomian glands.

b. Compound, with numerous lobules. Lacrymal glands, salivary glands, pancreas, prostate, Cowper's and Bartholine's glands, mammary glands, lungs.

4. *Tubular glands,* whose secerning elements have the form of tubes.

a. Simple, consisting of but one or some few tubes, terminating in blind extremities. Tubular gastric and intestinal glands, uterine glands, sudoriferous and ceruminous glands.

b. Compound, with numerous branches, and, perhaps, reticularly united canals. Testicles, kidneys.

Literature.—J. MÜLLER, *De Glandularum Secernentium Structura Penitiori.* Lips. 1830; H. MECKEL, *Mikrographie einiger Drüsenapparate niederer Thiere,* in MÜLL. *Arch.* 1846; FR. LEYDIG'S *Comparative Anatomical Treatises* in *Zeitsch. f. wiss. Zoologie, and Untersuch. über Fische und Reptilien.* Berl. 1853.

2. TISSUES OF CONNECTIVE SUBSTANCE.

§ 22. *General Characters of Connective Substance.*—The tissues belonging to this group, viz., mucous tissue, cartilage, elastic and connective tissue, as also the tissue of the bones and teeth, present, both in a histological and chemical point of view, such manifold differences, that it is, properly speaking, only the *genetical connection between them,* and their *correspondence in function,* which keeps them together. In the latter respect, connective substance serves as a support and investment for all the other parts of the body, and might even be designated with a still more general expression, viz., 'substance of support,' or 'sustentative substance.' As such, it forms, firstly, the solid framework of the whole body (cartilages, bones and ligaments of the internal skeleton; the external skeleton — except the horny structures — free cartilages and bones of internal parts); secondly, the investment of groups of organs, single organs or parts of organs (corium, mucous membranes, fibrous membranes, sheaths of muscles, nerves and glands, vessels); thirdly, and lastly, a packing or connecting material between individual organs and parts of organs (adipose tissue, medulla of bone, loose areolar tissue, vitreous humour, tendons). With regard to the *genetical connection* between the different tissues of connective substance, it is not to be considered as if one of these tissues were the highest which, during its development, runs successively through the form of all the others; on the contrary, this connection rather lies in the circumstance that they are developed from a similar genetic matter, in several parallel series, of which the members can be transformed into each other. If we start from the embryonal cellular tissue, from which the connective substance is developed, we obtain three members of the first series, viz., *mucous tissue*, *cartilage*, and *connective tissue*, including elastic tissue. In the two former, the embryonal cells have proceeded uniformly in their development, in the one case to cartilage-cells, in the other to cells of mucous tissue, an intermediate substance having at the same time arisen between them; whilst in connective tissue, they become transformed essentially according to two types, and are converted, firstly, into connective tissue *corpuscles*, and, secondly, into the proper *cells* of connective tissue; the latter of which pass into the fibrous matrix of this tissue, whilst the other either persist as cells, or are converted into elastic fibres. Now these three tissues are intimately related in so far as, firstly, cartilage and mucous tissue, as comparative histological and pathological facts (*Virchow*) more especially prove, present transitions, and may probably even be, in certain cases, converted into one another; secondly, they are also capable of becoming transformed into connective tissue, which is evidently the highest form, as the phenomena seen in the formation of the medulla of cartilage seem to prove. With regard to connective tissue, on the other hand, it cannot, owing to its complex structure, be directly transformed into cartilage and mucous tissue; but it very frequently happens that, firstly, its corpuscles assume all the characters of cartilage-cells, as in fibro-cartilage, and, secondly, that together with its fibrous substance arising from the cells, a homogeneous substance, containing mucus and albumen, develops itself, as in the gelatinoid embryonal connective tissue, which, perhaps, also occurs as a gelatiniferous substance, or is converted into such in certain cases, so that the affinity of connective tissue with cartilage and mucous tissue is not to be mistaken. It is in no way inconsistent with this intimate connection of the three tissues in question, that each of them, in the further course of development, may arrive at forms which present an important difference from the other two, and seem to render a metamorphosis into them impossible. As already remarked, these three tissues do not represent so many evolutional forms belonging to one and the same series, but rather, as it were, parallel conditions manifesting themselves throughout a larger group of tissues. Instances of such peculiar forms are afforded by the mucous tissue when its cells have vanished, reticular cartilage, and elastic tissue, in which last the gelatiniferous or white fibrous tissue is reduced to insignificance, and the specially transformed corpuscles come to predominate.

A more important proof of the intimate connection of the three tissues in question is, that, firstly, *all are capable of passing into osseous tissue;* and, secondly, *they are very frequently substituted, the one for the other, in the animal series.* With regard to the former point, the recent investigations, since those of *Sharpey* and myself, have shown with certainty that not only cartilage, but even connective tissue, may be converted into true bone, in which case its fibrous substance becomes ossified, and the corpuscles are transformed into bone-cells. Mucous tissue likewise appears, at least in abnormal conditions, capable of conversion into bone, as seen in ossifications occurring in the vitreous humour; so that all the three members of the first series of connective substance, however different they may be, may all lead to a similar result. All forms of connective substances can, likewise, mutually take the place of each other in one and the same organ, as is more especially observable in the skeleton, which appears in almost every modification of connective tissue, cartilage, and bone; further, in the skin, which not only repeats the different forms of mucous and connective tissues, but also presents osseous, and cartilaginous, and even dental formations of the most diverse kinds.

If, after this general consideration, we cast a glance at the individual parts which enter into the composition of connective substances, we observe the following:—The *matrix*, occurring in all of them, presents, in its development, two essentially different types. In connective tissue it is chiefly formed by *a coalescence of elongated* (perhaps, also, round) *cells*, whilst in mucous and cartilaginous tissue it is more especially *intercellular substance.* Yet, even in connective tissue, there is formed, in certain cases (in gelatinoid connective tissue), along with the matrix proceeding from cells, a distinct intercellular substance; while, on the other hand, in cartilages, the external secondary membranes of the cartilage-cells participate in the formation of the intermediate substance.

Apart from this, the matrix of the different connective substances agrees very much, being found, in different degrees, homogeneous, finely granular, striated, or even made up of separable fibrillæ, and in every degree of consistency, being mucous, gelatinous, firm, or even of cartilaginous and bony hardness.

In a *chemical* point of view, the variations of connective substance are just as great; for although it is found in many cases (bone, dentine and cement, true cartilage, and connective tissue generally) to yield gelatine and chondrin, yet the gelatinous composition of the matrix cannot by any means be acknowledged as characteristic of, and essential to connective substances; such a composition being wanting in many of them (connective substance of invertebrate animals, mucous tissue, central masses of the intervertebral cartilages, gelatinous tissue of fishes, homogeneous connective tissues of vertebrate animals, in part, etc.). No accurate chemical distinctive character of the matrix of connective substances can as yet be given; for although we know that it contains mucus, albumen, and colloid substances (in the intervertebral ligaments, *Virchow*), chondrin, gelatin, and a body similar to the substance of elastic tissue, yet not much is gained by this; and, as *Reichert* very properly remarks (*Bindeg.* p. 185), the task imposed upon us consists rather in demonstrating the genetical connection between these matters, and in showing that they are capable of being converted into one another, as has been already stated, with reference to the histological elements of connective substances. Nevertheless, this much may be remarked, that just as cartilage, bone, and fibrous connective tissue appear as the highest forms of connective substances, so also, in a chemical point of view, gelatin may be regarded as distinctive of a fully formed basal substance.

The cells scattered in the matrix of the connective tissues are of different kinds. By far the most interesting are those which may be designated by the general expression, *cells of connective substance.* These cells, in fact, occur in all structures formed of connective substance, and present a great uniformity in their several developmental conditions, as well as in their physiological significance. From the round shape which they possessed originally, and even retain in mucous tissue and most cartilages, they pass into the spindle or stellate form (cartilage cells of the cephalopoda, of certain cartilaginous fishes, of enchondromatous tumours, connective-tissue-corpuscles in the different forms of the connective tissue), and may even become connected with each other, to form anastomosing canals. Further, as long as they possess the round form, they very frequently present the peculiarity of excreting secondary membranes, and thus become transformed into thick-walled vesicles (cells in the true and reticulated cartilages, cartilage-cells in connective tissues), which are even capable of being metamorphosed similarly to the lignified and dotted vegetable cells (cartilage-cells in rachitic bones). When connective substance ossifies, the cells mentioned pass into different forms, as round, stellate, or elongated, as into the lacunæ and canaliculi of bone, or the tubules of the teeth, and then serve to transport the nourishing fluid into these structures; a function which, moreover, they possess in many connective tissues and in the cartilages, except that here they are not always so favourably constituted for this purpose. In connective tissue these cells frequently contain pigment, and all pigment-cells of connective substance belong to this category. But while all these cells, viz., those of mucous tissue and cartilage, colourless and pigmentous corpuscles of connective tissue, bone-cells, and dental canals, thus agree in all essential points, there occur, nevertheless, in certain connective-tissue-corpuscles, further peculiar metamorphoses, by which they are ultimately converted into *elastic fibres*, between which and the connective-substance-cells of other tissues no points of comparison are any longer discoverable. With regard to the chemical nature of the cells of connective substance, this much is certain, that their membranes consist originally of a protein compound, but, in the course of development, are frequently converted into a substance very closely allied to that of elastic tissue, whose fibres, indeed, arise from such cells. Hence it arises that, in most connective substances, the cells can be easily isolated on softening the matrix by boiling, or by maceration in acids or caustic alkalies. It is only in certain cases that the membranes of connective-substance-cells seem to yield gelatin, viz., in the external secondary membrane of cartilage-cells at the period of ossification, and, as it also appears, the cartilage-capsules in reticular cartilage.

Besides the above large and important group of cells in the tissue of connective substance, others occur, many of which, however, appear in such large proportions and apparent independence of the connective substance, that it is impossible to place them in a line with the proper cells of that substance. In this category I place fat-cells of all kinds, the cells of parenchymatous organs not referable to epithelial formations, such as the small cells in the red medulla of bone, those of the shut follicles of the intestine and spleen, the parenchymatous cells of the latter organ, and of the supra-renal capsules, the cells of the lymphatic glands; lastly, the morphological elements of the lymph and of the blood, which cells are all directly contained in larger and smaller spaces of connective substance, certain of which, viz., the capillaries, have, on account of their origin, even been regarded, and, perhaps, correctly, as homologous with the corpuscles of connective tissue (*Leydig*). Of all these the fat-cells are most intimately allied to connective substance, so that we can scarcely but classify them with the latter, and designate adipose tissue as a form of connective tissue. If we do this, it is but another step to bring into the same rank the tissues of the lymphatic glands, of the splenic pulp, and of the red medulla of bone, in which we find everywhere, along with the cells, bundles of connective tissue; and there would then result an almost gradual transition to those forms in which the cells appear in large numbers, alone and without any intermixture of connective substance, and are only contained in large spaces of the latter, like the nutritive fluid in the blood-vessels. Nevertheless, it appears to me proper, both on histological and physiological grounds, to distinguish between supporting, investing, and expletive connective tissues with their peculiar cells, and the formations contained in spaces within them. Whether or not these, like all the above-mentioned structures, arise with the connective substance from *one* primitive embryonal basis (the middle germinal layer, *Remak*), still it is evident, that they, just as well as the muscular and nervous tissues, which likewise originally consist of such cells, are entitled to a distinct place, which is not altered by the circumstance that certain of the cells in question enter into an intimate relation with connective tissue, and, like fat and marrow-cells, even support it in its functions. The above-mentioned spaces of connective substance may (in contradistinction to the *intra-cellular* cavities of the connective-tissue-corpuscles, lacunæ of bone, dental canals, etc.), be most fitly designated as its *intercellular spaces*, and the matters contained in them as intercellular fluid and intercellular parenchyma.

Literature.—C. B. REICHERT, *Vergleichende Beobachtungen über das Bindegewebe und die verwandten Gebilde.* Dorpat. 1854. VIRCHOW, *die Identität von Knochen-, Knorpel-. und Bindegewebskörperchen, so wie über Schleimgewebe,* in Würzb. Verhandlungen, 1851, ii. p. 150 and 314. DONDERS, in *Ned. Lancet,* 1851, July and August; and *Zeitschrift f. Wiss. Zool.* iii. p. 348. KÖLLIKER, *über die Entwickelung der sogenannten Kernfasern, der elastischen Fasern und des Bindegewebes,* in Würz. Verh. iii. p. 1. HENLE, in *Canst., Jahresb.,* 1851, 1852. v. HESSLING, in *Illust. Med. Zeitung,* 1852, pp. 54, 124, 162. C. B. REICHERT, *Zur Streitfrage über die Gebilde der Bindesubstanz,* in MÜLL. *Arch.,* 1852, p. 521. REMAK, *über die Entstehung des Bindegewebes und des Knorpels,*

[illegible] F. F. THIERFELDER, *de Regeneratione Tendinum* [illegible] LANGER, *die Anatomie der männlichen Brustdrüsen*, in [illegible] LEYDIG, *Unters. uber Rept. u. Fische*, 1853, p. 112.

§ 23. *Mucous Tissue.*—By this name I designate a tissue which, in man, exists only in the vitreous body, but which has very probably an extensive distribution in the lower animals. It consists of cells and a soft matrix, or even only of the latter, as the cells may disappear in the course of development. The cells are round or oblong, and contain a variable amount of matter, rich in protein: while the matrix appears as a homogeneous or striated mass, and owes its greater or less consistency to the quantity of mucus in its composition, which mucus appears to be very different in different animals. In the vitreous body of the embryo and child, which organ as yet can alone be referred to this tissue, the cells are pretty numerous, and uniformly scattered throughout the whole organ; whilst in fully formed animals, they are to be found only at its surface, or are wholly wanting. When comparative histology is farther advanced, it will, doubtless, be found that many other organs consist of this tissue; and I may, for the present, bring under it the substance of the disc of Medusæ, that of the swimming bladder and other parts of the Siphonophoræ, etc. Farther investigation would also, without doubt, bring out a diversity of chemical composition; and it will, perhaps, be necessary hereafter to select a more general expression for this tissue.

The name *Mucous Tissue* was lately applied by *Virchow* to designate the gelatinoid embryonal connective tissue, and then extended to that of the vitreous humour. In normal histology, there seems, for the present, no reason for assigning a place to a form of tissue of the composition of gelatinoid-connective tissue, since such a one never occurs in the fully developed body. I have, accordingly, reckoned only the vitreous body under the present head in the mean time. If, however, such a tissue shall be found to be permanent in animals, or the requirements of pathological Histology shall so demand, the definition given above can be readily enlarged, and a tissue classified under it, in which one part of the cells has become converted into a network, while the others have remained lying in the muciferous (albuminiferous) jelly.

Literature.—Compare the treatises of *Virchow*, cited in § 23, then of the same author; *Notiz über d. Glaskörper im Arch. f. path. Anat.* iv. p. 468. and v. 278.

§ 24. *Cartilage-Tissue.*—The cartilages consist of a firm, but elastic, bluish, milk-white, or yellowish substance, which, in point of structure, presents a two-fold condition; and appears, firstly, *as a simple parenchyma of cells;* and, secondly, *as a cell-tissue with a matrix between the elements.*

In form, the cartilage-cells present but little that is peculiar; they are mostly round or oblong, frequently flattened or fusiform, very rarely stellate (in Cephalopoda, Rays; in Enchondromatous growths). Their membrane is delicate at first; but subsequently becomes, in most places, covered on its outer side with a second layer, which bears the same relation to it as the cellulose-membrane of vegetable-cells does to the primordial utricle. Accordingly, there are two parts to be distinguished in cartilage-cells: 1. *The proper cell*, or *the primordial utricle* (the cartilage-corpuscle of authors), an extremely delicate-walled cell, filled with contents sometimes clear and fluid, sometimes dark and firm, together with a nucleus; and, 2. *The external secondary membrane*, or *the cartilage-capsule* (the cartilage-lacuna of authors), a firm, clear, or yellowish layer, formed by an excretion of the primordial utricle, and closely surrounding the inner cell. By continued excretion from the latter, deposited upon its inner surface, the outer cell-wall may attain a laminated appearance, and a very considerable thickness. The contents of the delicate cartilage-cell coagulate and shrink up on the addition of many re-agents, and even of water; so that an interval is formed between it and its capsule (fig. 14—1, 2), and it becomes converted into a dark and jagged corpuscle, without any distinct nucleus, the nature of which it is difficult to recognise.

In the cartilage-cells we find, very frequently, a *multiplication of cells*, which process is effected by division of the primordial utricle within the cartilage-capsule. Around the secondary cells there are then formed new cartilage-capsules; whilst the capsules of the mother-cells gradually blend with the intermediate substance, which accordingly owes its origin, in part at least, to the cells. The *matrix* is either homogeneous, finely granular, or fibrous, even with distinct and separable fibres. The *chemical characters* of cartilage-tissue are as yet but little known. This much is certain, that the cells and the matrix do not consist of the same materials; that is to say, the membranes of the proper cartilage-cells do not dissolve on boiling, and long resist the action of alkalies and acids—properties which distinguish them from the gelatiniferous substances, but approximate

Fig. 14.

Three human cartilage-cells, magnified 350 times. 1. From the epiglottis, readily separable, with somewhat shrunk primordial utricle. 2. From an articular cartilage, with strongly contracted primordial utricle. 3. From an ossifying cartilage, with unaltered primordial utricle, the two latter cells with thin cartilage capsule, one with thicker. *a*. Cartilage-capsule. *b*. Primordial utricle, with the cell contents and nucleus, which in 2 is concealed.

them to elastic tissue. On the other hand, the cartilage-capsules, or the secondary membranes of the cartilage-cells, appear to pass gradually into a gelatiniferous substance, as may be concluded from their becoming more or less altered on boiling, and particularly from the capsules of the mother-cells, which are more or less blended with the matrix, being dissolved by boiling. The contents of the cells coagulate in water and in dilute organic acids, and readily dissolve in alkalies. The matrix, in the majority of cartilages, yields chondrin; and it is only in reticular cartilages that it is composed of a material very nearly related to the substance of elastic tissue. Accordingly, the cartilages which consist only of cartilage-cells, and reticular cartilage, yield, on boiling in water, little or no gelatine, and the presence of that substance is not characteristic of cartilage-tissue.

In a *physiological* point of view, the firmness and elasticity of cartilage is especially to be noticed, properties by which the cartilages are of use in various ways. In *growing cartilages*, the nutritive change is very energetic, and in certain places they always contain numerous *blood-vessels*, in special canals, and, as I have shown in the *septum nasi* of the calf, even *nerves*. The cartilages are developed from the primitive embryonal cell-masses; the cells of the latter becoming converted into cartilage-cells, and, at least in many cases, a homogeneous intercellular substance appearing between them, which is derived from transuded constituents of the blood. The *growth* of cartilage is effected, firstly, by *endogenous cell-multiplication*, traces of which are always discernible even in fully-formed cartilage; and, secondly, by the deposition of an intermediate substance from the blood-plasma, between the cells, which in every case at first solely constitute the cartilage. The intermediate substance, according to *Schwann's* observations, yields at first no chondrin, even in the true cartilages, and subsequently increases more and more in quantity. A growth of cartilage, by the *apposition of new layers outside the part of the cartilage already formed*, as *Gerlach* assumes, has been nowhere proved with certainty. In fully developed cartilage, the change of material is certainly not energetic; and, apart from the vessels of the perichondrium covering many cartilages, and those of the adjoining bone, no special means are provided for effecting such change, except in the cartilages of some mammals (septum of the nose) and of the Plagiostoma; in which latter, according to *Leydig*, even in old animals, there occur vascular canals (ray), or anastomosing, fusiform, or stellate cartilage-cells (shark, chimæra, acipenser).

In old age, the matrix of certain true cartilages is apt to become fibrous, and to resemble, in its chemical characters, that of reticular cartilages; which, coupled with the fact, that, in certain places (especially in the arytenoid cartilages of Mammals) reticular and true cartilages pass continuously into each other, proves that *these two kinds of cartilage are not decidedly separated from each other.* In old age, it is not at all unusual for the true cartilages to ossify, vessels and medulla being at the same time developed in them. The cartilages do not possess the *power of regeneration,* and *wounds of cartilage are not healed by cartilage-substance;* on the other hand, *accidental formations of cartilage* are by no means rare.

The different kinds of cartilage-tissue are the following:—

a. Cartilage-tissue without any basal substance, or *cartilage-cell-parenchyma.* To this head belongs the *chorda dorsalis* of embryos, and of many fully developed fishes; further, many fœtal cartilages, the cartilages of the branchial laminæ of fishes, in part, and those of the external ear of many Mammals.

Fig. 15.

Human cartilage-cells, from the whitish layer of the cricoid cartilage; magnified 350 times.

b. Cartilage-tissue with a matrix.

1. *With a more homogeneous matrix, yielding chondrin, true cartilage, hyaline cartilage* (fig. 15). This is found in the larger cartilages of the respiratory organs, in those of the joints, in the costal and nasal cartilages, as well as immediately covering the bones in all symphyses and synchondroses, on the *sulcus ossis cuboidei,* and in the cartilages of ossification in the fœtus.

Fig. 16.

A piece of the human epiglottis; magnified 350 times.

2. *With a fibrous connecting mass, yielding little or no chondrin. Reticular cartilage. Yellow cartilage* (fig. 16); fibro-cartilages in part, epiglottis, *cartil. Santorinianæ, Wrisbergianæ.* Cartilage of the ear and of the Eustachian tube, *intervertebral ligaments* in part.

The recognition of the true structure of the cartilage-cells is of quite recent date, and first became possible when observers began to scrutinise more closely the relation of the cellular elements to each other in connective tissue, cartilage, and bone. It was first demonstrated by *Virchow*, that the cartilage-corpuscles of authors, or the contents of the cartilage-lacunæ, are really delicate-walled cells, and not merely cell-contents, as had been generally assumed. Now, since it had been previously shown by myself and others, in opposition to *Reichert* and *Bergmann*, that the cartilage lacunæ possess distinct walls, and are separable cellular structures, it was but natural to apply the doctrine of the primordial utricle, and of the external secondary cell-membranes, to cartilage-cells, as was accordingly done by *Remak* and myself (see antea). The primordial utricle of the cartilage-cells is most readily observable in reticular cartilages; and, owing to their peculiar matrix, these are also best adapted for convincing the most incredulous of the existence of cartilage capsules as distinct structures different from the matrix, and belonging to the cartilage-cells. In true cartilages, moreover, the cartilage-capsules can frequently be very readily isolated, particularly, as *Donders* long ago pointed out, by boiling, and the proper cartilage-cell also recognised, the latter especially in ossifying cartilages (*Virchow*).

Literature.—MECKAUER, *De penitiori Cartilaginum Structurâ Diss.*, Vratisl., 1836. J. MÜLLER, in *Poggendorf's Annalen*, 1836, p. 293. RATHKE, in *Fror. Not.*, 1847, p. 306. A. BERGMANN, *De Cartilaginibus Disq. micr.*, Mitaviæ, 1850. Compare, further, the Treatises of *Virchow* and *Remak*, cited above, under Connective Tissue; also F. HOPPE, *über die Gewebelemente der Knorpel, Knochen und Zähne*, in VIRCHOW'S *Arch.*, v. p. 170.

§ 25. *Elastic Tissue.*—The elements of the elastic tissue are darkly contoured, cylindrical or riband-like fibres, varying in their diameter from immeasurable fineness to 0·003‴, or even 0·005‴ (in animals even 0·008‴) in thickness, and when they lie together in masses, presenting a yellowish colour. These *elastic fibres*, as they are called, are, when fully formed, completely solid, but may subsequently contain small cavities at certain places, which in one animal, the giraffe (QUEKETT, *Histological Catalogue*, i.), appear so regular, that the fibres acquire a beautiful transversely striped appearance. The borders of the elastic fibres are, as a rule, quite even, but appear, in rarer cases, jagged, or, as *Virchow* observed in newly-formed tissues, even beset with very many longer and shorter pointed processes. Hitherto the *nuclear fibres* have been separated from the *elastic fibres*. Since, however, the former differ in nothing but their diameter from the latter; further, since all elastic fibres are originally just as fine as the

Fig. 17.

Elastic network, from the *tunica media* of the pulmonary artery of the horse, with holes in the fibres; magnified 350 times.

nuclear fibres; and since, lastly, the latter are not developed from nuclei alone, it is better to discard the name *nuclear fibres* entirely, and to divide the elastic fibres into *finer* and *thicker*.

Fig. 18.

Network of fine elastic fibres, from the peritoneum of a child. Magnified 350 times.

The elastic fibres occur either *isolated* as longer or shorter fibres, straight or spirally wound round other parts (bundles of connective tissue, nerves), and, in this case, usually belong to the finer kind; or, *anastomosing*, with fibres of various thickness, and then form the so-called *elastic fibrous network* (fig. 18). This is sometimes spread out in form of a membrane, and sometimes traverses other tissues at different depths. The *elastic membranes* represent a modification of this elastic fibrous network, in which the fibres are so densely interwoven as to give rise to a continuous membrane, which, in extreme cases, retains no indication of its former nature, and appears as a perfectly homogeneous membrane with small openings (fenestrated membrane, *Henle*) (fig. 19).

Fig. 19.

Elastic membrane, from the *tunica media* of the carotid of the horse. Magnified 350 times.

In its *chemical* relations, elastic tissue presents very definite reactions, still the composition of its substance is not yet accurately known. In cold concentrated acetic acid, the elastic fibres, except that they swell out somewhat, are not at all affected; on the other hand, by some days continued boiling in the acid, they gradually dissolve. Nitric acid renders them yellow; *Millon's* re-agent for proteine compounds, red; whilst they are not reddened by sulphuric acid and sugar. In moderately concentrated solution of caustic potash, elastic tissue remains for a long time unaltered in the cold, except that it swells up and becomes somewhat pale; on being heated with that solution for days, it is transformed into a gelatinous mass. This tissue does not dissolve in water, even when boiled for sixty hours; but after being boiled for thirty hours at 160° (320° F.) in *Papin's* digester, it is converted into a brownish substance, smelling like gelatine, but not gelatinizing, which is precipitated by tannic acid, tincture of iodine, and corrosive sublimate, but not by the other tests of chondrin.

In a *physiological point of view*, we have, above all, to notice the great elasticity of this tissue, by which it supports very essentially the motory organs, and also plays an important part in other respects, *e.g.*, in the vocal cords. With regard to its development, the supposition of *Schwann*, that this tissue arises from cells, is rendered more and more probable by the more recent investigations. In fact, in all parts of the embryo which afterwards contain elastic tissue, peculiar fusiform or stellate, and sharply-pointed cells can be recognised, which, by their coalescence, produce long fibres or networks, in which the situation of the body, or central part, of the original cell may for some time be distinguished by a swelling of the fibre, with an elongated nucleus in the interior. The fibres not unfrequently persist in this condition of stellate anastomosing cells, or connective tissue-corpuscles (*Virchow*), as, *e.g.*, in the tendons and the cornea, in ligaments and ligamentous discs, in the corium, in mucous membranes, etc.; in which places, moreover, fully formed elastic fibres are generally present. In other cases, every trace of their former cellular nature disappears, so that uniform fibres, or fibrous networks, arise. These may then persist throughout life as fine elastic fibres and networks, or, by increase in thickness, pass into the coarser form of this tissue. The homogeneous elastic membranes are nothing but close elastic networks, the fibres of which have become so broad that only narrow spaces remain between them. The fully developed elastic tissue appears scarcely to be subject to any nutritive change of material; at any rate, it is, in the ordinary sense, non-vascular, even when in large masses. On the other hand, *Virchow's* supposition, that the undeveloped forms of this tissue, particularly the connective-tissue-corpuscles, contain juices, and help in effecting nutrition, is obviously well founded; and we may, perhaps, be warranted in placing them, physiologically, on a parallel with the fine canalicular system in the bones and teeth; on which account I will call them *plasm-cells*, and their processes *plasm-tubes*. It is not known that the elastic tissue is ever regenerated; on the other hand, new formations of it are not rare.

Fig. 20.

Stellate formative cells, of fine elastic fibres, from the tendo-Achillis of a newly-born child. Magnified 350 times.

The elastic fibres rarely appear in large masses, but are frequently found intermixed with connective tissue, either in the form of isolated fibres, or of networks of various kinds. As true elastic organs, are to be mentioned—

a. The *elastic ligaments*, in which the tissue, with but a slight intermixture of connective tissue, and almost without vessels and nerves, occurs, so to speak, pure. To this division belong the *ligamenta subflava* of the vertebræ, the *lig. nuchæ*, certain ligaments of the larynx, the stylo-hyoid ligament, and the suspensory ligament of the penis.

b. The *elastic membranes*, which either appear as fibrous networks, or as fenestrated membranes, and occur in the coats of the vessels, particularly in those of the arteries, in the trachea and bronchi, and in the *fascia superficialis*.

Literature.—A. EULENBERG, *De Tela elastica*, Berol. 1836. See also the Treatises cited in § 24.

§ 26. *Connective or Areolar Tissue.*—The elementary parts found in connective tissue may be divided into such as are essential and never-failing, and such as are more accidental, or occurring only in certain places. To the former belong the proper *connective* or *areolar tissue*, with its sometimes more homogeneous, sometimes fibrous substance, as also the more *homogeneous connective tissue;* to the others are to be reckoned the cells of connective substance occurring, it is true, almost everywhere, in different forms, as plasm-cells, cartilage-cells, or elastic fibres, also the fat-cells and certain other cells without any well-defined character. Besides, many connective tissues also contain a not inconsiderable quantity of an interstitial substance. The proper connective tissue usually appears as *fibrous*, and breaks up, more or less distinctly, into small divisions —the *bundles*,—each of which, again, consists of a number of very fine *fibrils*. The fibrils are distinguished from the finest elastic fibres and muscular fibrils, which, in other respects, resemble them most, by their small diameter (0·0003‴ to 0·0005‴), their pale colour, their homogeneous appearance, and the entire absence of striation. They are held together by means of a small quantity of a clear uniting matter, and thus form the *bundles*, as they are called, which resemble, in many respects, those of the transversely striped muscles, yet differ from them by the absence of a special envelope, such as the sarcolemma, and by their smaller average diameter (0·004‴ to 0·005‴). They are either long, slightly undulating cords, of equal thickness throughout, which are not connected with each other directly, but, being arranged in various ways, parallel to and over each other, form large secondary and tertiary bundles and lamellæ; or they coalesce to form a meshwork *similar to an elastic network*, and constitute what I have called the *reticular connective tissue*. In other cases, but less commonly, the bundles do not appear to be composed of distinct fibrils, but are more homogeneous, as in the neurilemma, where they are known as *Remak's* fibres. Besides this form of areolar tissue, there exists a second rarer one, in which neither bundles nor fibrillæ can be clearly distinguished, and there is nothing but a finely granular, or slightly striated, or even quite homogeneous clear substance, spread out in the form of a membrane, or appearing in large masses — *homogeneous* (or *Reichert's*) *connective tissue*. The other elements occurring in connective tissue, except the already mentioned plasm-cells and their derivatives, offer nothing requiring to be noted here, and will be spoken of in their proper place, in the special part of the work. We may now only further mention, that the plasm-cells and fine elastic fibres are very regularly distributed in many of the fibrous forms of connective tissue, and principally run regularly between the bundles, the demarcation of which chiefly depends upon these elements. An *interstitial substance* is, perhaps, also present in small quantity between the bundles in all kinds of connective tissue, although it cannot be directly demonstrated in the more compact forms; on the other hand, it is not unfrequently distinguishable in loose connective tissue, yet, in certain cases, it is not easy to say whether it is to be regarded as an amorphous substance, or as homogeneous connective tissue derived from cells.

Fig. 21.

Loose areolar tissue, with fat-cells; of man. Magnified 350 times.

In its chemical relations, the connective tissue is well known. The proper connective substance yields, on boiling with water, ordinary gelatine. There is also a fluid contained in its tissue, the composition of which, on account of its small quantity, has not yet been investigated. It is only where it is collected in larger amount, as in the gelatinous connective tissue of embryos, that the presence of much albumen and mucus in it can be readily demonstrated. The chemical constitution of homogeneous connective tissue is less known; but it would seem, in many places, to approach the elastic tissue in its composition.

Connective tissue is, according to its nature, serviceable in the animal frame, sometimes as a firm, unyielding substance, sometimes as affording a soft support to vessels, nerves, and glands, and sometimes, finally, as a pliant material, filling up interstices, and facilitating change of position. Wherever elastic elements occur in it in large quantity, its purpose is altered; and when it contains a large number of fat-cells, or cartilage-cells, it attains a softness or a resistance not occurring elsewhere.

Fig. 22.

Formative cells of areolar tissue, from the skin of the trunk of a sheep's embryo, seven lines long; magnified 350 times. *a*. Cell without any indication of fibrils; *b*. with commencing, and *c*., with distinct fibrils.

Connective tissue is invariably developed from cells, — the fibrous form from fusiform or stellate vesicles, which unite to form long fibres or networks, and, at the same time, break up into fibrillæ, frequently, even, before their coalescence. The mode in which this happens is not yet quite made out, still it is most probable that the cells, contemporaneously with their elongation, pass, with their membranes and contents, into a homogeneous, pulpy mass, which then breaks up into a bundle of fine fibrils and a small quantity of uniting substance. The homogeneous connective tissue has, as yet, been but little followed in its development; but wherever it is collected in large masses, it appears, in general, to arise like the other, by the coalescence of round or elongated cells, in which the metamorphosis has only gone the length of forming a homogeneous mass, but not of fibrillation. On the other hand, certain homogeneous membranes of connective tissue are, perhaps, to be regarded as representing merely an intercellular substance. When the bundles of connective tissue have once begun, they increase in length and thickness, like the elastic fibres, till they have attained the size which they possess in the adult; and subsequently, also, there arise in many places, new elements which become connected with those already present. The perfect connective tissue is, when unmixed, almost destitute of vessels, and as to nutrition, stands in any case very low in the scale; on which account, it is scarcely ever the subject of diseased processes. It is different with the vascular connective tissue; but in this case the morbid changes do not depend upon any peculiar condition of the connective tissue itself, but are occasioned by the vessels, fat-cells, etc., contained in it. Among the higher elementary parts, the bundles of the connective tissue and the elastic fibres stand lowest in the scale, and are, accordingly, regenerated with the greatest facility.

The combination of the different elements of connective tissue takes place in various ways, and the following forms are the best marked:—

1. *Firm connective tissue* ("connective tissue of determinate form," *Henle*). In this the elements are intimately connected, and in such a manner, that simple organs of a perfectly determinate form arise from it. To this division belong:

a. The tendons and ligaments, with parallel bundles, united by looser connective tissue into larger cords, between which a certain number of anastomosing plasm-cells, fine elastic fibres and elastic networks are regularly disposed.

b. The fibro-cartilages. Having the structure of tendons and ligaments, but with numerous cartilage or plasm-cells interspersed. They occur either as special organs, as the interarticular fibro-cartilages, and the circumferential, such as the glenoid and cotyloid *(labra glenoidea)*, or at particular places in other organs formed of connective tissue, especially in tendons, sheaths of tendons, and ligaments.

c. The fibrous membranes. These are distinguished from *a.* only by the frequent interweaving of the bundles, and by generally containing a larger proportion of elastic fibres. To this division belong:

1. *The muscular fasciæ*, which have more the structure of tendons.

2. *The periosteum* and *perichondrium*, containing, in some parts, a great many elastic fibres.

3. *The white dense envelope of many soft organs*, as the dura mater, the neurilemma, the sclerotic and cornea, the fibrous coat of the spleen and kidney, the *tunica albuginea* of the ovaries, testicles, penis, and clitoris. In the last-mentioned parts, and in the spleen, these envelopes, which contain firm connective tissue and numerous fine elastic fibres, are continued into the interior of the organs, and here, mixed to some extent with smooth muscular fibres, form a more or less perfect frame-work, which sometimes appears in the form of partitions, or of a stroma, or of a trabecular network. A modification occurs in the cornea, in which the connective tissue is transparent, contains numerous plasm-cells, and yields, on boiling with water, chondrin, but no gelatine.

d. The serous membranes. These are formed of connective tissue, which contains much fine elastic tissue, and consists of bundles interwoven in various ways, or actually anastomosing together in a reticular manner, but which may also, in some cases, present a more homogeneous character, especially at the surface of the membrane. The serous membranes, which are always destitute of glands, and have, on the whole, but few vessels and nerves, line the cavities containing the viscera, and are rendered smooth and shining upon the inner surface by an epithelial covering. They do not necessarily form shut sacs, as was formerly believed, but may have openings (abdominal opening of the Fallopian tubes), or be absent altogether over certain parts of the surface of the cavity, as upon articular cartilages. In other cases, their basis of connective tissue may be wanting, and then the epithelium lies on another structure, as in the case of the so-called outer lamina of the cerebral arachnoid. To these membranes belong: 1. the *proper serous membranes*, as the arachnoid, the pleura, the pericardium, peritoneum, and the *tunica vaginalis*, all of which secrete normally only a minute quantity of a serous fluid; and 2. the *synovial membranes* or capsules of the joints, the *bursæ mucosæ* and *sheaths of tendons*, which yield a viscid, yellowish material, the synovia, which contains albumen and mucus.

e. The corium. This consists of a dense, felt-like network of bundles of connective tissue, which at the surface, and in the papillæ, gives place to an indistinctly fibrillated, and partly, even, more homogeneous tissue, and contains a great number of finer and coarser elastic networks, also plasm-cells and numerous vessels and nerves. The corium supports the cutaneous papillæ on its external surface, and is here covered by the epidermis, with which it forms the external integument; and it is separated from the deeper parts by a soft tissue generally rich in fat, the subcutaneous connective tissue, or the adipose membrane *(panniculus adiposus)*.

f. The mucous membranes (tunicæ mucosæ). These consist essentially of a basis of connective tissue containing vessels and nerves— the proper mucous membrane — of an epithelial layer covering it, and of submucous connective tissue, which, in the intestine, is called *tunica nervea*. The first is similar in structure to the corium, but softer, and not unfrequently poor in elastic tissue and plasm-cells. From the serous membranes the mucous membranes are, in general, distinguished by their richness in vessels, their greater thickness, their richness in glands, and their mucous secretion, which is chiefly attributable *to their soft epithelial covering*; yet there exist mucous membranes which are just as thin and glandless as serous membranes; and, on the other hand, the synovial capsules approach the mucous membranes by their richness in blood and the nature of their secretion. The mucous membranes and the external skin correspond in all their principal parts, so that the transitions occurring between them, as at the lips, eyelids, and elsewhere, are not surprising. To the mucous membranes belong the innermost coat of the intestinal canal, the lining of the nasal fossæ and accessory cavities, the lining of the Eustachian tube, tympanum and mastoid cells, and the conjunctiva. All the larger glands possess a distinct mucous membrane in their excretory ducts: thus, the lungs are provided with such a membrane from the glottis to the finest bronchia; the liver, in the larger hepatic ducts and in the gall-bladder; the pancreas, in the pancreatic duct; the urinary and sexual organs, in the urethra, bladder, ureter, pelvis of the kidneys, vagina, uterus, and Fallopian tubes — in the mammary ducts and sacs — and in the seminal vesicles and vas deferens. In all these glands, the mucous lining ultimately passes into the membrane of the gland-tubes and vesicles; so that these may be regarded as being formed by an attenuated mucous membrane. The same may be said of the smaller glands, as those of the intestine, which are directly continuous with large expansions of mucous membrane; only in this case, we should have to regard the small glands of the skin also as being formed by processes of the latter. Since both development and physiology, to some extent, support this view, so far, at least, it appears warranted. Still it must not be forgotten, that many *membranæ propriæ* are not of the nature of connective tissue, but appear as excretions of the cells of the gland-tubes, so that the secerning glandular elements still preserve a certain independence.

g. The coats of the veins and lymphatics, the adventitious coat of the arteries, and *the endocardium*, consist of a connective tissue not unlike that of the fibrous membranes, and of finer and coarser elastic fibrous networks, with which, in the veins, smooth muscular fibres may be mixed.

h. The so-called *vascular tunics*, to which belong the pia mater with the choroid plexus, the choroid and iris. All contain numerous vessels, which, however, are destined less for these tissues themselves than for the nourishment of other organs. For supporting the vessels either ordinary connective tissue is employed, destitute of elastic fibres (iris, pia mater), with parallel, matted or anastomosing bundles, or a homogeneous connective tissue (choroid plexus, choroid coat), with which, as in the choroid, other peculiar elements may be associated, viz., anastomosing cells, filled more or less with pigment, which are probably to be ranked with the plasm-cells of connective tissue.

i. The homogeneous membranes of connective tissue. In many organs, membranes are met with which agree in aspect, and partly in chemical nature, with connective tissue, but do not possess distinct bundles and fibrillæ, and rather appear homogeneous. Under this head I reckon, the homogeneous tissues which often envelop the bundles of the arachnoid separately or several together, the neurilemma of small nervous trunks, the hyaloid membrane, the envelopes of the Malpighian corpuscles of the spleen, and of the glandular follicles of the alimentary canal (tonsils, follicles of the tongue, solitary and Peyer's glands). Of the envelopes of glandular elements, all those which contain nuclei (or plasm-cells) belong to this division, as those of the testicles, Graafian follicles, and of certain racemose and tubular glands; on the other hand, I cannot class with connective tissues the homogeneous, non-nucleated, true *membranæ propriæ*, such as those occurring along with the former in the seminal tubules and Graafian follicles, and especially those of the uriniferous tubules, on which point I would refer to § 16. In like manner, the capsule of the lens, the *Membrana Demoursii*, *Membrana limitans*, and the sheath of the chorda dorsalis, also appear to me to owe their origin to the excretion of matter from cells, and not to belong to this division; while, as regards the structureless membranes occurring under epithelial and epidermic layers, or the *basement membranes*, I refrain, for the present, from giving an opinion. There is much in favour of the view, that they are only the outermost layer of the membrane (of connective tissue) which they limit, while it is also possible that they may belong genetically to the cells which they support.

k. Loose or areolar connective tissue (amorphous connective tissue, *Henle*). This consists of a lax network of anastomosing or variously interwoven bundles of connective tissue, which occur in greater or less quantities between the organs and their individual parts. It appears in two forms: 1. *As adipose tissue*, when numerous fat-cells are contained in the meshes of a connective tissue poor in elastic fibres and plasm-cells. 2. *As ordinary loose connective tissue*, when the fat-cells are scanty or altogether absent.

l. Adipose tissue chiefly occurs in the integument as *panniculus adiposus*; in the large cylindrical bones, as yellow bone-marrow;

in the orbit; around the kidneys; in the mesentery and omenta; around the spinal cord; on nerves and vessels; and in muscles.

m. Ordinary areolar connective tissue, which is sometimes quite poor in elastic fibres and plasm-cells, and sometimes abounds in them, is found most extensively between the organs seated in the neck, the thoracic, abdominal, and pelvic cavities; along the course of all vessels and nerves; and in the interior of muscles, nerves, and glands.

In certain places, as in the vertebral canal and medulla of cartilage, it is of a *gelatinous nature*, like embryonal loose connective tissue, and then contains in its meshes a fluid sometimes like serum, sometimes containing mucus and albumen.

Literature.—ZELINSKY, *De Telis Collam Edentibus.* Dorp. 1852. Diss. Also the treatises cited in § 224.

§ 27. *Osseous Tissue.*—Structurally, osseous tissue essentially consists of a matrix, and of numerous microscopic cavities 0·006‴ to 0·014‴ in length, 0·003‴ to 0·007‴ in breadth, and 0·002‴ to 0·004‴ in thickness, disseminated in it,—the *lacunæ* (bone corpuscles of authors). The former, which is of a white colour, is sometimes more homogeneous, sometimes finely granular, very frequently lamellated, and, from its intimate union with calcareous salts, hard and brittle.

The lacunæ are generally lenticular in shape, and are, in most cases, connected to each other by numerous fine processes, the *canaliculi*, by which some of them also open upon the outer surface of the bones, and others into the larger and smaller medullary spaces in the interior. The lacunæ and canaliculi contain a pellucid matter, which may be designated as the nutrient fluid of the bones; and, in many cases, a cell-nucleus also appears to be enclosed in the lacunæ, and may, perhaps, be present in all. Besides these two most important elements, which are never absent in the bones of the higher animals, most of the bones contain numerous *vessels* and *nerves*, and frequently, also, a special substance supporting these, the *medulla*. This consists either of ordinary *adipose tissue*, or of a loose, scanty areolar tissue, with but few fat-cells and numerous proper marrow-cells, as they are called. These soft parts fill up the large central cavities of the bones, and those of the spongy substance; they also, at least in part, occupy the narrow canals traversing the compact substance, the *vascular* or

Haversian canals, which open abundantly on the outer and inner surfaces of the bones.

The matrix of bones consists of an intimate mixture of an organic substance, agreeing entirely in nature with that of connective tissue, and certain inorganic constituents, of which the phosphate and carbonate of lime form the principal part. The fluid contained in the lacunæ and canaliculi is not accurately known; but it probably chiefly contains albumen, fat, and salts, like the blood-plasma. By their firmness and hardness, the bones serve to support the soft parts, and to enclose and protect them. They occasionally, also, fulfil special ends, as, for example, the auditory ossicles and the parts of the labyrinth which conduct the waves of sound.

Fig. 23.

From the inner surface of the parietal bone of a new-born child; magnified 300 times. *a*. Bone with lacunæ still pale and soft. *b*. Border of the same. *c*. Ossifying blastema, with its fibres and cells. *B*. Three of these cells, magnified 350 times.

The *development* of bone takes place in two modes: first, by the *metamorphosis of true cartilage;* and secondly, by that of *ordinary connective tissue*. In both cases, the cells are converted into lacunæ: in the former, the cartilage-cells; in the latter, the plasm-cells; and this takes place after two somewhat different types. When cartilage ossifies, the cartilage-cells, produce a new generation of soft cells and these only assuming a stellated form, are transformed into lacunæ. On the other hand, when connective tissue ossifies, its cells undergo no greater changes; that is to say, while the fibrous substance of the connective tissue takes up calcareous salts, the cells grow out in a stellate manner and anastomose, or when they pre-existed as stellate anastomosing plasm-cells, simply remain as such. *Thus the lacunæ of bone are in every case cells, and, accordingly, would be better denominated bone-cells.* In all bones, as *Virchow* first discovered, these bone-cells can be readily isolated by maceration in acids and alkalies, as well as by boiling. The matrix of the bones arises, in the *one case, by the* ossification of a new-formed soft substance, the matrix of cartilage being dissolved; in the other, by the deposition of calcareous salts in the fibrous substance of connective tissue, but presents in both cases, as far as is known, essentially the same chemical and histological characters. The *nutritive changes* of the bones are very energetic, and are accomplished through the agency of the vessels of the periosteum, and by those of the marrow and Haversian canals, when they exist. The bones possess a great capability of regeneration, so that they readily re-unite when broken; and extensive losses of substance may be repaired, or even entire bones restored, when the periosteum has been spared. Accidental formations of bone are also very common.

Osseous tissue occurs, first, in the bones of the skeleton, to which belong, also, the auditory ossicles and the hyoid bone; secondly, in the bones of the muscular system, as the sesamoid bones and the ossifications in tendons; thirdly, in the *crusta petrosa* or *cement* of the teeth. Many cartilages ossify pretty regularly in old age, as the costal and laryngeal cartilages.

Dentine, or *ivory*, may be regarded as a modification of osseous tissue, in which, instead of isolated lacunæ, long canals, the *dentinal tubes*, occur, and which, also, presents some differences in chemical composition. The mode of its development leads us to regard it as an osseous substance, whose cells have grown out into long tubules which anastomose with each other by fine processes; a view which also explains the numerous formations observable in animals between the typical dentine and osseous tissue (see below, the section on the Teeth).

It has been supposed till now, that the stellated bone-cells in part arise from cartilage-cells, in part from cells of connective tissue; but *H. Müller* has shown, in a very remarkable paper, that true cartilage-cells never are transformed into real stellated lacunæ, and that these arise only from the cells of connective tissue, and from a young growth of cells, formed by a multiplication of the cartilage cells. The only exception of this rule seems to occur in rachitic bones, in which, as I have shown, cartilage-cells are metamorphosed into peculiar stellated lacunæ.

Literature.—DEUTSCH, *De penitiori Ossium Structurâ Observationes Diss.* Vrat. 1834. MIESCHER, *De Inflammatione Ossium eorumque Anatome generali.* Berol. 1836. SCHWANN, Art. *Knochengewebe*, in *Berl. Encyclop. Wörterb. der med. Wiss.*, vol. xx. p. 102. TOMES, Art. *Osseous Tissue*, in *Cyclop. of Anat.*, iii. H. MÜLLER, in *Zeitsch. f. Wiss. Zool.*, Bd. ix.

3. Muscular Tissue.

§ 28. *General Characters.*—The further our knowledge of the contractile tissues advances, the more clearly does it appear that the decided separation, hitherto assumed to exist between smooth and transversely striped animal and organic muscular fibres, can no longer be maintained. For besides the well-known fact, that the animal muscular fibres of certain creatures do not, in any respect, differ in structure from smooth muscles, inasmuch as they consist of a homogeneous substance, without either fibrils or striæ, it has also been shown that smooth muscles exist, whose elements are transversely striated, like the animal muscular fibres of the higher animals. Moreover, the mode of development of the contractile tissues and their physiological phenomena are by no means favourable to a division of them in the accustomed sense. With regard to the former, it follows, from the observations of *Lebert* and *Remak* on the muscles of frogs, and from mine on those of mammalia, frogs, and many invertebrata, that even the long, striated muscular fibres are nothing else than *single cells* (see below); and, therefore, the old distinction between muscular fibres formed by single cells, and fibres representing many cells, cannot longer be maintained.

Nor is the case different in a physiological point of view, seeing that it can scarcely be doubted, that the essential distinctions observed in the functions of the animal and organic muscles depend only on their relations to the nervous system. Since, moreover, no differences in chemical constitution are known between the various contractile elements, it appears, on every ground, reasonable to place them together in *one* group. Nevertheless, it appears to me advisable, especially with reference to the muscles of man and the higher animals, to retain the two well-known designations in order to indicate the subdivision of this group, and to employ the mode of development as the principle of division. For although a great diversity exists in the form of the contractile elements, yet it is obvious, that the great majority of them are divisible into two classes: 1. those which consist of a cell with one nucleus; and 2. those which contain a great number of nuclei. Now, since the most important distinction, which, apart from their relation to the nervous system, prevails between the contractile elements is, perhaps, connected with this difference,—the distinction, namely, that the one class of muscles are capable of limited and independent contractions, even in their smallest portions, while the other are *capable only of total* contraction, I am the more induced to lay down, as subdivisions of the muscular tissue, 1. that of the *contractile cells*; and 2. that of the *contractile fibres*.

§ 29. *Tissue of the Contractile Cells, or of the Smooth Muscles.* The smooth, also vegetative or organic muscles, consist essentially of microscopic, generally fusiform, rarely short and broad fibres—*the contractile, or muscular fibre-cells*, as they are called by me. Each of these elements, measuring on average 0·02‴ to 0·04‴ in length, 0·002‴ to 0·003‴ in breadth, has the signification of an elongated cell; yet, with some few exceptions (muscular fibres of the gravid uterus), presents no differentiation of contents and envelope, but consists of an apparently homogeneous, sometimes finely granular, or slightly striated substance, in which a cylindrical (rod-shaped) long cell-nucleus is invariably found in the middle of the fibre. These fibre-cells are united by means of a not directly observable connecting matter, to form flat or roundish cords, the *bundles* of the smooth muscles, which are then connected by delicate envelopes of connective tissue and fine elastic fibres,—a kind of *perimysium*,—to form larger masses, in which numerous *vessels*, and a relatively small number of *nerves*, are distributed.

Fig. 24.

Muscular fibre-cells, from human arteries. 1. From the arteria poplitea; *a* without, *b* with, acetic acid. 2. From a branch of the arteria tibialis antica; *a*, nuclei of the fibres. Magnified 350 times.

The chief elements of the smooth muscles consist, chemically, of a nitrogenous substance allied to fibrin, the *fibrin of muscle or syntonin (Lehmann)*, which, so far as is known, is distinguished from the fibrin of the blood only by its not dissolving in nitrate and carbonate of potash, while it dissolves very readily in diluted hydrochloric acid. The *physiological* importance of the smooth muscles lies in their contractile property, by which they very materially aid in the functions of the viscera, in which, by reason of the shortness of their elements, they can bring about perfectly local changes of form. The *development* of their elements takes place simply by the elongation of round cells and the union of the cell-membranes and contents to form a homogeneous soft mass. The process of nutrition may be assumed as being energetic in the smooth muscles, as the more recent investigations of the fluid permeating them more especially shows; which fluid, according to *Lehmann*, has, for the most part, an acid reaction, and contains lactic, acetic, and butyric acid, also kreatin and inosite; and, as is further proved by the frequent occurrence of physiological (in the uterus) and pathological hypertrophies and atrophies of them. It is not known whether smooth muscles are ever regenerated, or whether losses of substance are repaired by a similar tissue; but new formations of them appear to occur in tumours of the uterus.

In the human body, the smooth muscular tissue nowhere forms large isolated muscles, as in the case of the recto-penal muscles of mammals, for example, but occurs either scattered in the connective tissue, or in the form of *muscular membranes*. In both cases, its bundles are either arranged parallel to each other, or united to form networks; and, even in man, are connected in many places with *tendons of elastic tissue*, as first detected by me in the tracheal muscles, and in the cutaneous feather-muscles of birds. It is found in the following places:

1. In the *alimentary canal*, the smooth muscular tissue forms, firstly, the muscular coat from the lower half of the œsophagus, where smooth bundles are still intermingled with transversely striped fibres, to the internal sphincter of the anus; secondly, the muscular layer of the mucous coat, from the œsophagus to the anus; and, thirdly, individual muscular bundles in the villi.

2. In the *respiratory organs* a muscular layer appears in the trachea, on the posterior wall, and accompanies the bronchia as far as their finest branches, as a complete circular coat.

3. In the *salivary glands*, this tissue is found only in the Whartonian ducts; and even there but scantily, and as an incomplete layer.

4. The *liver* possesses a complete muscular layer in the gall-bladder, and smooth muscular tissue sparingly in the *ductus choledochus*.

5. The *spleen*, in many animals, possesses, in its envelopes and trabeculæ, smooth muscular fibres intermixed with connective tissue and elastic fibres.

6. In the *urinary organs* the smooth muscles appear in the pelvis and calices of the kidney and form a complete muscular coat in the ureters and bladder, but, on the other hand, are found but scantily in the urethra.

7. The *female sexual organs* possess smooth muscles in the Fallopian tubes, in the uterus, where their elements are enormously

developed during pregnancy, and attain up to ¼ of a line in length, in the vagina, in the cavernous bodies of the external genitals, and in the broad ligaments of the uterus at various places.

8. In the *male sexual organs* they occur in the *dartos*, between the *tunica vaginalis communis* and *propria*, in the *epididymis*, the *vas deferens*, the seminal vesicles, the prostate, around Cowper's glands, and in the *corpora cavernosa* of the penis.

9. In the *vascular system*, smooth muscles are met with in the tunica media of all arteries, especially the smaller ones, in that of most veins, and of the lymphatic vessels, except the finest; further, in lymphatic glands (*Heyfelder*), and in the external or adventitious coat of many veins. The muscular elements in vessels of middling size are everywhere fusiform fibre-cells; in the large arteries, on the other hand, they are short plates, often resembling certain forms of pavement epithelium, and in the smallest arteries, oblong, or even roundish cells; both of which forms are to be regarded as being more undeveloped.

10. In the *eye*, smooth muscles form the sphincter and dilator of the pupil and the *tensor choroideæ*.

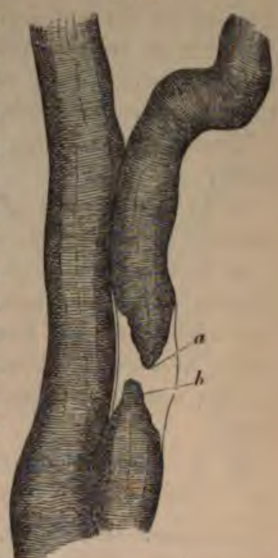
11. In the *skin*, this tissue, besides entering into the formation of the *dartos*, occurs in the form of small muscles attached to the hair follicles, also in the areola of the nipple, in the nipple itself, and in many sudoriparous and ceruminous glands.

Formerly, the elements of the smooth muscles were regarded as long bands, containing numerous nuclei, and, like the transversely striped fibres, were considered as arising by the coalescence of many cells arranged in series. In 1847, I showed that this is not the case; but that, on the contrary, the elements of these muscles are only simple, modified cells; and demonstrated, at the same time, that these contractile fibre-cells occur wherever contractile connective tissue has been assumed to exist, and are also to be met with in other parts where they were not supposed to exist.

Literature.—Kölliker, *Ueber den Bau und die Verbreitung der glatten Muskeln.*, in the *Mittheil. der Naturf. Gesellschaft in Zürich*, 1847, p. 18; and *Zeitschrift für Wissenschaftl. Zoologie*, vol. i., 1849. Lister, in the *Micros. Journal*, and *Trans. of Royal Society of Edinburgh.*

§ 30. *Tissue of the Muscular Fibres, or Transversely Striped Muscles.*—The elements of this tissue consist essentially of *muscular fibres*, or *muscular primitive bundles*, as they are called, each of which represents a bundle, 0·004‴ to 0·03‴ in thickness, of fine fibrillæ, enclosed by a special, homogeneous, delicate, elastic envelope, the *sarcolemma*. The fibrils are generally regularly nodular, appearing, as it were, to consist of a number of particles ranged in a linear series, and thereby producing the transversely striated character of the muscular fibre; or they appear smooth, and then the fibres or primitive bundles appear striated longitudinally. Besides these fibrils, the muscular fibres contain nothing but a small quantity of a viscid substance uniting them, and a certain number of roundish or elongated cell-nuclei, which generally lie upon the inner surface of the sarcolemma. The *union* of the muscular fibres to form muscles and muscular coats, is effected either by their being arranged parallel to each other, or by their connection in form of true *networks*. Moreover, they are enclosed by an envelope, of greater or less firmness, named the *perimysium*, which consists of connective tissue always containing fine elastic fibres, and sometimes fat-cells; and they are encircled by numerous *blood-vessels* and *nerves*.

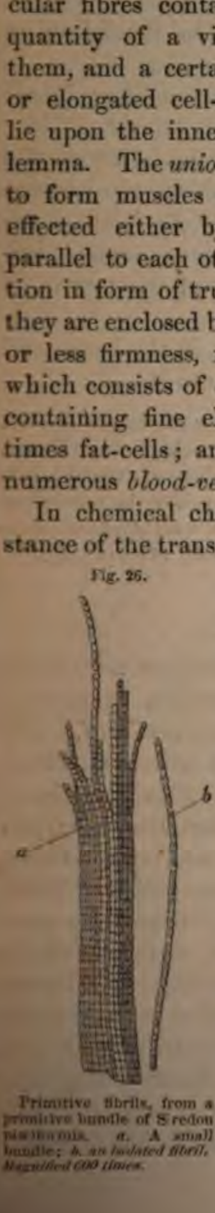
Fig. 25.



Two human muscular fibres; magnified 350 times. In the one the bundle of fibrillæ (*b*.) is torn, and the sarcolemma (*a*) seen as an empty tube.

In chemical characters, the chief substance of the transversely striped muscular fibres entirely agrees with the *syntonin*, mentioned in the preceding section. The sarcolemma strongly resists the action of alkalies and acids, while the nuclei present the ordinary characters of these structures. A fluid of an acid reaction can be pressed out of the muscles, in which *Liebig* and *Scherer* have discovered an interesting series of non-nitrogenous and nitrogenous products of decomposition of the muscular tissue.

Fig. 26.



Primitive fibrils, from a primitive bundle of Sredon [illegible]. *a*. A small bundle; *b*. an isolated fibril. Magnified 600 times.

The transversely striated muscles are, in a high degree, capable of contracting; and, by reason of their length, of bringing about very considerable total effects. Their elements arise by the transformation of single cells into long fibres with many nuclei; in some cases, also, by coalescence of stellate cells. In the fully-developed condition of these muscles, the nutritive process is very active, as is evident from the various products of decomposition mentioned above, and also from the circumstance, that their functional activity is soon extinguished on the stoppage of the circulation of the blood in them. Wounds of muscles never heal by means of transversely striated muscular substance; on the other hand, accidental formations of this tissue are met with, although rarely.

Transversely striped muscular tissue occurs in the following parts:

1. In the *muscles of the trunk and of the extremities; in the external muscles of the eye, and all the muscles of the ear.*

2. In the *muscles of many viscera;* as the larynx, pharynx, the tongue, and œsophagus (upper half), the end of the rectum (*sphincter externus, levator ani*), the genitals (*bulbo-ischio-cavernosus, urethralis communis transversus, transversus perinæi, cremaster,* muscular fibres of the round ligaments of the uterus, in part).

3. *In certain parts of the vascular system,* viz., in the heart, and in the walls of the large veins where they open into it.

Literature.—W. Bowman, article *Muscle and Muscular Motion,* in *Cyclop. of Anat.;* and *On the Minute Structure of Voluntary Muscle,* in *Phil. Trans.,* 1840, 1841. J. Holst, *De Structurâ Musculorum in genere et Annulatorum Musculis in specie.* Dorp., 1846. M. Barry, *Neue Unters. über die schraubenförmige Beschaffenheit der Elementarfasern der Muskeln, nebst Beobachtungen über die muskulöse Natur der Flimmerhärchen* (Müll. *Arch.,* 1850, p. 529).

4. Nervous Tissue.

§ 31. The essential elements of the nervous tissue are of two kinds, *nerve-tubes* and *nerve-cells.* The nerve-tubes, or nervous primitive fibres, are either *medullated* or *non-medullated.* The former consist of three parts: of a structureless delicate envelope, *sheath of the primitive tube;* of a soft but elastic fibre, situated in the centre, the *central or axial fibre* (axis-cylinder, *Purkinje;* primitive band, *Remak*); and of a viscid, diffluent white layer between these two, the *medullary sheath.* In the non-medullated fibres, which, in man, occur only in certain peripheral terminal expansions (retina, organ of hearing, organ of smelling, cornea, Pacinian bodies), the structureless envelope encloses nothing but a homogeneous or finely granular, clear substance, which appears to agree with the axial fibre of the other tubes, or, at any rate, may be considered analogous to it, so that the medullary sheath is absent in these fibres. The primitive nerve-fibres are of very various dimensions, and, accordingly, they may be distinguished as fine, 0·0005‴

to 0·002‴; middle sized, 0·002‴ to 0·004‴; and thick, 0·004‴ to 0·01‴. They are either isolated in their course, the fibres running from the centre to the periphery, or they divide, especially in their terminal distribution, into a larger or smaller number of branches; or, lastly, they form true *anastomoses* and *networks*. All nerve-fibres are connected with nerve-cells; either arising from them, or being interrupted in their course by interpolated ganglionic cells. These *nerve-cells*, or, as they are called in the ganglia, *ganglionic cells, ganglionic globules*, have the ordinary characters of cells. Their membrane presents nothing

Fig. 27.

Human nerve-tubes; magnified 350 times. Three fine, one of which is varicose; one middling thick, and simply contoured; and three thick, two of which are double contoured, and one with granular contents.

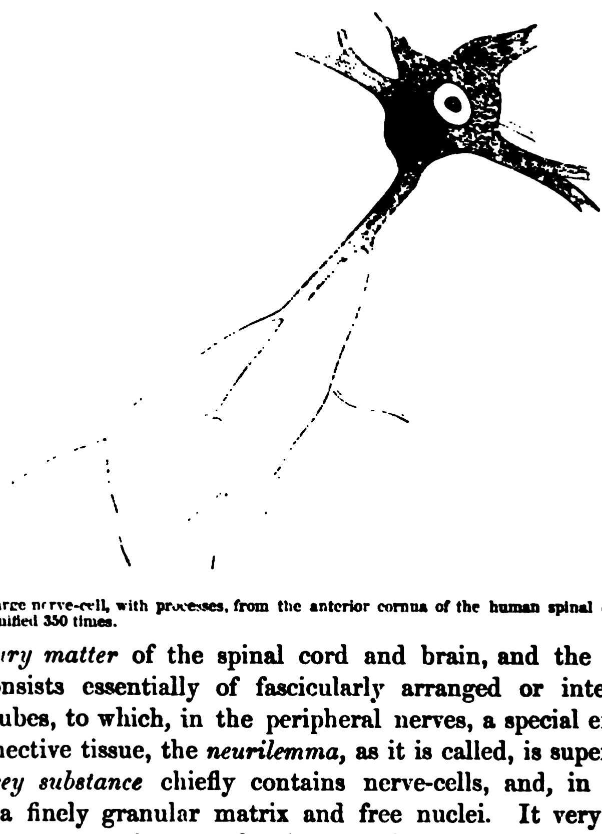
Fig. 28.

Ganglionic globule from the pike (*bipolar*), running out at the two extremities into dark-bordered nerve-tubes; treated with arsenious acid, and magnified 350 times. *a*. Envelope of the globule; *b*. sheath of the nerve; *c*. medulla of the nerve; *d*. axial-fibre connected with the contents *e*, of the ganglionic globule retracted from the envelope.

peculiar, except that it is frequently very delicate, or even, as in the large central masses, perhaps entirely disappears. The contents are finely granular and pulpy, very frequently with pigment, and invariably include a beautiful vesicular nucleus with a large nucleolus. In *size*, the nerve-cells vary from 0·003‴ to 0·04‴; and with respect to their *form*, they are chiefly distinguished into round, fusiform, and stellate. The two latter kinds consist of nerve-cells running out into two, three, or as many as eight and more processes, which, in some cases, pass, after a short course, into medullated nerve-tubes, in others, present a greater independence, inasmuch as, while they have precisely the aspect of non-medullated nerves, they often run to great distances, and, at the same time, ramify variously. How these processes ultimately terminate, whether free or by connection with nerve-fibres, or by anastomoses with similar processes, is not yet made out; but it appears not improbable, that all these three possibilities occur in different situations.

Nerve-fibres and nerve-cells unite to form two substances, very differently constituted in their extremes, the *grey and white substance.* The latter forms the *white medulla,* as it is called, or the

Fig. 29.



Large nerve-cell, with processes, from the anterior cornua of the human spinal cord. Magnified 350 times.

medullary matter of the spinal cord and brain, and the nerves; and consists essentially of fascicularly arranged or interwoven nerve-tubes, to which, in the peripheral nerves, a special envelope of connective tissue, the *neurilemma,* as it is called, is superadded. The *grey substance* chiefly contains nerve-cells, and, in certain places, a finely granular matrix and free nuclei. It very rarely, however, occurs quite pure, but is generally intermingled, more or less, with nerve-tubes. This is especially the case in the majority of the ganglia, in the grey substance of the spinal cord, and in the so-called cerebral ganglia; while, on the other hand, in the grey cortex of the brain and cerebellum, it is, in some places, almost destitute of nerve-fibres. This substance is much more largely supplied with vessels than the white, and, in the peripheral ganglia, contains different forms of connective tissue for enveloping its different parts.

The chemical composition of the nervous substances is still far from being investigated with sufficient accuracy. In the white substance, the central fibre of the nerve-tube consists of a protein compound, very similar to the fibrin of muscle; the medullary sheath, chiefly of different kinds of fats; and the envelope of a substance similar to the sarcolemma. The grey substance chiefly contains an albuminoid body, besides some fat.

The *physiological importance* of the nervous tissue consists, firstly, in its being the medium of motion and sensation; secondly, in its exerting a certain influence upon the vegetative functions; and thirdly, in serving as a substratum for the faculties of the mind; in all which functions the grey substance appears, from all that has been hitherto ascertained, to play the more important part, the white serving more as a conducting medium between it and the organs.

The nerve-cells are developed from the ordinary formative cells of the embryo and the nerve-tubes by the coalescence of numerous similar cells, of a roundish, fusiform, or stellate shape, with envelope and contents; to which, in the medullated tubes, a peculiar alteration of their contents is superadded, in consequence of which they divide into a more consistent central filament, and a softer sheath. The process of nutrition must, especially in the grey substance, be very energetic, as the large quantity of blood which flows to that substance sufficiently proves; yet the products of decomposition of this tissue are still wholly unknown. The white nervous substance is readily enough regenerated in the peripheral nerves, and, as appears, in the spinal cord also. *Accidental formations* of nerve-tubes have been observed in pathological new formations; nay, it even appears, according to an observation of *Virchow*, that abnormal formations of grey substance may occur.

The organs composed of nervous substance are: the *peripheral nervous cords, nervous membranes* and *nervous tubes, the ganglia, the spinal cord*, and *the brain.*

Literature.—G. VALENTIN, *Ueber den Verlauf und die letzen Enden der Nerven*, in *Nov Act. Natur. Curios.*, vol. xviii. t. i. REMAK, *Observ. Anatomicæ et Microsc. de Syst. Nerv. Struct.*, Berol., 1838 A. HANNOVER, *Recherches Microscopiques sur le Système Nerveux*, Copenhagen, 1844. R. WAGNER, *Neue Unters. über den Bau und die Endigungen der Nerven und die Structur der Ganglien*, Leipzig, 1847; and *Neurol. Untersuchungen*, in Gött. Anz., 1850, p. 34. *BIDDER and REICHERT, Zur Lehre vom Verhältniss der Ganglienkörper* *zu den Nervenfasern*, Leipzig, 1847. CH. ROBIN, in *l'Inst.*, 1846, Nos. 687—690; and 1848, No. 733. KÖLLIKER, *Neurologische Bemerkungen*, in *Zeitsch. f. wiss. Zool.*, i. p. 135.

5. TISSUE OF THE VASCULAR GLANDS.

§ 32. Under the name *vascular glands* are comprehended a series of organs whose common character consists in this, that they prepare, from *the blood or other juices in a special glandular tissue*, certain matters which are not conveyed away by special permanent, or occasionally-formed excretory ducts, but simply by transudation from the tissue, and are then employed, in one way or another, for the purposes of the organism. Although this very general definition may include organs which it will, perhaps, be necessary hereafter to separate, yet, owing to our very defective knowledge of these structures, it seems to be the only one possible, without too much anticipating the special discussion of them.

The essential glandular tissue of the organs in question presents itself in the following forms:

1. *As a parenchyma of larger or smaller cells*, embedded in a *stroma* of connective tissue. *Supra-renal capsules, anterior lobe of the pituitary body.* Here the cells attain 0·04''', and more in size; and then contain, besides a granular mass, numerous nuclei and secondary cells.

2. *As closed follicles*, with *an envelope of connective tissue* and contents consisting of *nuclei, cells*, and *some fluid.* To this division I reckon:

a. The *solitary follicles* of the stomach and intestine; and

b. The *aggregated follicles* of the small intestine, or the patches of *Peyer* (in animals, also, of the stomach and large intestine), both of which contain numerous blood-vessels in the interior of the follicles.

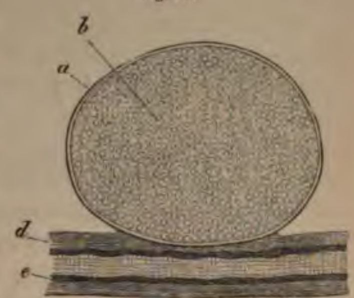
c. The *follicular glands of the root of the tongue, the tonsils*, and *the pharyngeal follicles*, which contain, in the walls of their cavities, numerous shut follicles like the above-mentioned, and probably, also, having vessels in their interior.

d. The *lymphatic glands*, the glandular parenchyma of which consists of round follicles, similar to those of the Peyerian glands, but opening into each other, and directly connected with the lymphatic vessels.

3. *As a cell-parenchyma, supported by trabeculæ of connective tissue*, containing, like the above, *numerous closed follicles. Spleen.*

The chemical nature of these more or less vascular organs is still but little known. Those under 1 and 2, as also the follicles of 3, contain much protein and fat in their tissue; while, on the other hand, the rest of the parenchyma of the spleen contains peculiar substances, not yet fully investigated, which indicate an energetic process of decomposition. Their physiological functions are just as little known; and it may suffice to mention here, that in the spleen, the thymus, the supra-renal capsules, and pituitary body, it can only be the blood which supplies them with materials, and the blood-vessels and lymphatics, which again take up the substance prepared by the glands. In the follicles of the oral cavity and of the fauces, the latter is effused into the larger recesses of these organs, and ultimately into the cavities mentioned; whilst, as to the intestinal follicles, it is doubtful whether they secrete matter into the intestine, or absorb it from the latter and discharge it into the vessels. In the lymphatic glands, the lymphatic vessels conduct their fluid into the glandular follicles and take it up again from them, now rich in lymph-cells. The development of the vascular glands is still very obscure; yet this much appears certain, that they are developed either from the fibrous layer of the intestine, or from the same blastema which produces the sexual glands. The change of material is very energetic in most of these glandular structures, as is shown by their large quantity of blood, and their liability to disease; but the pituitary and supra-renal body may, perhaps, occupy a subordinate position in this respect.

Fig. 30.



A Malpighian corpuscle, from the spleen of the ox; magnified 150 times. *a.* Wall of the corpuscle; *b.* contents; *c.* wall of the artery on which it is seated; *d.* sheath of the same.

Literature.—A. ECKER, art. *Blutgefässdrüsen*, in WAGNER'S *Handw. d. Phys.*, vol. iv. 1840.

SPECIAL HISTOLOGY.

OF THE EXTERNAL INTEGUMENT.

I.—Of the Skin Proper.

A. CUTIS.

§ 33. The *external skin* (fig. 31) consists essentially of an internal layer, composed principally of connective tissue, and abundant in vessels and nerves, the true skin, *cutis, derma* (fig. 31, *c. d.*): and of an external covering made up of cells only, the *epidermis* (fig. 31, *a. b.*); and, in addition, many peculiar glandular and horny organs appertain to it.

Fig. 31.

Vertical section through the skin of the ball of the thumb, transversely through two ridges of the cutis; magnified 20 times. *a*, Horny layer of epidermis; *b*. its mucous layer: *c*. corium; *d*. panniculus adiposus (upper parts); *e*. papillæ of the cutis; *f*. fat globules; *g*. sudoriparous glands; *h*. their canals; *i*. sweat-pores.

The *cutis* or *derma* may again be subdivided into two layers: the subcutaneous cellular tissue, *tela cellulosa subcutanea*, and the corium proper (fig. 31, *c.*); the latter of which, from its richness in vessels and nerves, constitutes the most important part of the external integument.

§ 34. The *subcutaneous cellular tissue (tela cellulosa subcutanea)* is a moderately compact membrane, formed chiefly of connective tissue, which, in most parts of the body, incloses within its meshes a considerable quantity of fat-cells (fig. 31, *f.*), and thus appears as a fatty layer (*panniculus adiposus*), of variable thickness. In some localities, however, *e.g.*, in the ear, eyelids, scrotum, penis, and nymphæ, it contains very little or even no fat, and measures only $\frac{1}{4}$ to $\frac{2}{3}$ of a line. The most internal layer of the subcutaneous cellular tissue, which upon the trunk and thighs presents a tolerably firm fatless expansion, the *fascia superficialis*, lies upon various organs, as fasciæ of muscles, periosteum, perichondrium, muscles, and the deeper collections of fat; and is connected, sometimes more loosely, sometimes more firmly, with them.

The external surface of the subcutaneous cellular tissue is, for the most part, firmly attached to the *corium*, particularly where hair-follicles dip into it, as on the head; on the other hand, when it forms a thick, adipose layer, it can be easily separated.

§ 35. The proper *corium* is a compact and but slightly elastic membrane, formed likewise principally of connective tissue. In the thicker parts, it presents two, not, however, very distinctly separated layers, which may be designated the *reticular* and the *papillary*. The *reticular part of the corium* forms the inner layer, and presents a white, reticulated, in its deepest portions often distinctly stratified, membrane, which contains, more especially, the hair-follicles and glands of the skin, together with a considerable quantity of fat. The *papillary part* is the reddish-grey external portion of the *corium*, situated immediately below the *epidermis*, which, in its dense firm tissue, contains the upper part of the hair-follicles and cutaneous glands, and the ultimate expansions of the vessels and nerves of the skin. Its most important constituents are the papillæ of the *corium*, which, according to their internal structure, may be divided into two species, *vascular* and *nervous* (fig. 32). They are small, semi-transparent, pliant, but tolerably firm prominences of the external surface of the *corium*, which are generally conical or club-shaped, but in certain places run out into several points (*compound papillæ*). As regards number and situation, it may be observed, that the papillæ of the matrix of the nail, of the palm of the hand, and of the sole of the foot, are very numerous (*E. H. Weber* calculates upon one square line of the

Fig. 32.

Compound papillæ of the surface of the hand, with two, three, and four points. *a*. Base of a papillæ; *bb*. their separate processes; *cc*. processes of papillæ, whose base is not visible. Magnified 60 diameters.

palm, 81 compound or 150 to 200 smaller *papillæ*; *Meissner*, upon the palmar surface of the finger, 400), and arranged partly regularly in two chief series (fig. 33), each of which contains from 2 to 5 *papillæ* abreast, seated upon linear elevations — $\frac{1}{10}$ to $\frac{1}{3}$ of a line broad, and $\frac{1}{20}$ to $\frac{1}{6}$ of a line high — the *ridges of the corium*, whose course, as they are visible externally on the epidermis, does not require further description. In other places the papillæ are less regularly distributed; either very near to each other, as on the labia minora, the clitoris, the penis, and the nipple, or more scattered, as on the limbs (except the parts of them above mentioned) — on the scrotum, neck, chest, abdomen, and back. The size of the *papillæ* varies pretty considerably, and is, upon an average, from $\frac{1}{40}$ to $\frac{1}{22}$ of a line. The longest *papillæ* are to be found on the sole of the foot, the palm of the hand, the nipple, the bed of the nails, and on the *labia minora*. Their breadth is generally $\frac{3}{4}$ to $\frac{1}{2}$ of their length.

Fig. 33.

Horizontal section of the skin of the heel through the apices of the papillæ of one entire and two half ridges. *a*. Horny layer of epidermis between the ridges; *b*. stratum Malpighii of the epidermis; *c*. papillæ; *d*. stratum Malpighii between the papillæ, belonging to their common base; *e*. sweat canals. Magnified 60 diameters.

The thickness of the corium varies from $\frac{1}{6}$ to $1\frac{1}{2}$ line, and in most places amounts to a $\frac{1}{4}$ or $\frac{3}{4}$ of a line. It presents most of the chemical characters of connective tissue, of which chiefly it is composed. It has little tendency to putrify, and none at all when treated with vegetable matters containing tannic acid, by which it is tanned or converted into leather. By boiling in water, it is resolved into gelatin.

§ 36. The cutis consists principally of *connective* and *elastic tissue*, and contains, besides, *smooth muscles*, *fat-cells*, *blood-vessels*, and *lymphatics* in large quantity.

The connective tissue consists of the usual bundles, which are partly connected in the form of a network, as in the subcutaneous cellular tissue; partly in the form of larger secondary bundles, *trabeculæ* and *laminæ* of various kinds. In the panniculus adiposus there are between these numerous larger and smaller spaces filled with fat; whilst in the *fascia superficialis*, and in the corium, their connection is very intimate, particularly in the latter, where they form a very compact tissue, with traces of stratification.—In the *papillæ*, and at the surface of the corium in general, the fibrous structure is not very evident; and in place of it there often appears a more homogeneous tissue, which seems to be limited towards the epidermis by a structureless basement membrane.

The *bursæ mucosæ subcutaneæ* are nothing but large, simple, or partially divided cavities in the subcutaneous cellular tissue, in the *fascia superficialis* (bursa olecrani), or between the *laminæ* of the *fascia muscularis* (bursa patellæ). Their internal walls, smooth but uneven, are composed of ordinary connective tissue, without an epithelium, and enclose a somewhat viscid, clear fluid.

The *elastic tissue* is to be found in almost all parts of the cutis in great abundance, yet, for the most part, much more sparingly than the connective tissue. Sometimes it appears in the form of genuine elastic membranes, which may even present a resemblance to the most compact elastic networks of the arteries, as in the *fascia superficialis* of the abdomen and thigh; but more usually it assumes the shape of a more open network of coarser or finer fibres, as in the *corium* proper. The *papillæ* and *panniculus adiposus* possess only fine fibres, and isolated or anastomosing plasm-cells, although the latter tissue may, in parts, be entirely destitute of them.

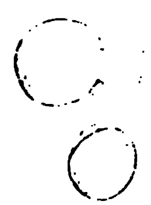
Smooth muscles, according to my researches, occur more extensively in the skin than has hitherto been supposed, viz., 1. in the subcutaneous cellular tissue of the *scrotum*, which owes its name (*tunica dartos*) to this circumstance; in that of the *penis*, together with the prepuce and anterior part of the perinæum, where, as yellow bundles (whose elements have been described in § 29), measuring $\frac{1}{5}$ or even $\frac{1}{2}$ a line, they run partly in the neighbourhood of vessels and nerves, partly more isolated in the connective tissue. All these bundles are united with one another, so as to form a network, and, for the most part, run parallel to the *raphe* of the *scrotum* and the long axis of the penis, although, and especially in the latter, thick bundles not unfrequently occur, having a transverse direction.

2. In the *areola* of the *nipple*, the smooth muscles, which are more developed in the female sex, are arranged in a circular layer, in which they become more pronounced from without inwards, as far as the base of the nipple; and from the breadth of their

… their yellowish-red, … eye In the *nipple* … particularly, and be- … form a dense network, … of the milk-gland

… with in the super- … corium, in all … fig. 34), in the … roundish bundles … of a line broad … exception, either … alongside o… … and sebaceous … These muscles arise from … portions of the … beneath the *epidermis* … by means of several little … small tendons (*Lister*) … towards the hair-follicles … attached to the former … their base.

… cells is pre-eminently the … lie here in the form of … smaller masses or lobules … of the areolar tissue. Each fat … tissue, in which the … and consists either of a single … a variable number of smaller and … of which again has a delicate covering of … According to *Todd* and *Bowman*, even every cell has its special covering and vessels; but although this is true in many cases, it certainly does not apply to all In the corium the fat-cells prevail most in the deeper portions around the hair-follicles and glands, and they are altogether wanting in the papillary layer. In individuals in moderately good condition the fat-cells are invariably round or oval, from 0·01‴ to 0·06‴ in diameter, dark contoured, and filled with fluid pale yellow fat, in the form of a single drop



Two fat-cells, from the medulla of the human femur. *a.* Nuclei; *b.* membranes of the cells; *c.* fat-globule. Magnified 350 times.

They have a parietal nucleus, which, however, is not easily rendered perceptible. In lean persons, on the other hand, cells of this sort are not common, and forms occur which deviate more or less from the preceding, viz., 1. *Granular cells*, containing numerous small fat-drops; these occur in whitish-yellow fat-lobules. 2. *Fat-cells containing serum* (in small yellow, or brownish-red lobules), which, together with the more or less exhausted fat, which appears in the form of a single, dark-coloured globule, contain a clear fluid and an evident nucleus, and are considerably smaller than the normal cells — from 0·01‴ to 0·015‴. 3. *Cells destitute of fat, and containing only serum*, with a distinct nucleus and a delicate or thickened membrane; these are found in the more jelly-like fat, or are mixed with others; they occur, also, in *anasarca*. 4. Lastly. *Fat-cells containing crystals;* these either include, in addition to a fat-drop, from one to four stellate groups of needle-shaped crystals (of *margarin*), or are entirely filled with acicular crystals. The former occur among normal cells; the latter in white fat. According to *Dr. Roscher*, of Norway, such crystals can be artificially produced in all, or almost all, fat-cells, by drying them; and it therefore is not improbable, that the crystals which are found in the dead body are formed after death. *Robin* and *Verdeil* observed that crystals of margarine were formed in the fat-globules of warm milk on cooling.

§ 38. *Vessels of the Skin.*—In the subcutaneous cellular tissue the arteries entering the skin furnish many small branches to the hair-follicles (see below), the fat-lobules and the smooth muscles, and form a network of capillaries, which is, for the most part, wide, but sometimes, though more rarely, rather close in its meshes, as especially in the fat-lobules. More superficially, the arteries supply the sudoriparous and sebaceous glands (see *infra*); give branches, but not many, to terminate in the inner or reticular part of the corium; and, finally, penetrate into the most external portion of the papillary layer, and into the papillæ themselves, when they end in a fine and close network of capillaries. These invariably consist, wherever papillæ are present, of two portions: first, of a horizontal plexus lying immediately under the surface covered by the epidermis, with wider meshes and larger vessels (from 0·01‴ to 0·05‴), and also closer meshes formed of capillaries (from 0·003‴ to 0·005‴); and, secondly, of numerous *loops* of finer or coarser vessels (from 0.003‴ to 0·004‴ in most places, and, according to *Meissner*, from 0·004‴ to 0.01‴, and even larger, on the *sole of the foot and palm*), which supply the papillæ. With certain exceptions, it is only the vascular papillæ which possess such capillary loops, the simple papillæ one loop, the branched several loops, which extend, either in the axis or more towards the surface, near to the apex, and present a gently waving or well-marked tortuous course, or are even twisted round each other in a spiral form.

Fig. 26.

Vessels of the papillæ of one entire and two half ridges of [illegible]. After Berres.

The large trunks of the *lymphatic vessels* can be easily recognised in the subcutaneous cellular tissue, and are very numerous. In the corium itself, various anatomists have demonstrated the lymphatic vessels by means of injections of mercury. All agree in this, that they exhibit an uncommonly dense network of fine vessels, measuring, according to *Krause*, from $\frac{1}{18}$ to $\frac{1}{20}$ of a line; that in the deeper parts the meshes become wider, the vessels larger, and, finally, communicate by single trunks with the vessels of the subcutaneous tissue. Still, it is not yet known whether these plexuses are the real origins of the lymphatics of the skin.

§ 39. *Nerves.*—The skin, in the portion next the epidermis, especially in certain places, is one of the structures of the frame most abundantly provided with nerves, while, in the deeper regions, it is remarkable for their scantiness. In the *panniculus adiposus* and the *fascia superficialis* no nerves have been hitherto recognised, except those which pass through those parts to the cutis, or proceed to the hairs, glands, smooth muscles, and Pacinian bodies, of which we shall afterwards speak. In the corium itself, the trunks which pass through the areolæ of its inner surface ascend gradually, continually giving off branches, but without actually forming terminal expansions, towards the papillary layers. Here, anastomosing frequently, they form rich *terminal plexuses*, in which deeper and more superficial portions can be distinctly distinguished; the former composed of fine branches, containing several primitive fibres, with wide meshes; the latter of single fibres, or of pairs of fibres, with narrow interstices. In the latter, or the finer terminal plexus, there also occur (whether in all the fibres is not yet determined) real *bifurcations of the primitive fibres of the nerves*; and from the plexus itself, at least in certain places (particularly on the palm of the hand, the sole of the foot, and the margins of the lips), one to four, but, in general, two, nerve-fibres finally pass into the base of certain papillæ, and, running towards their apices, there unite in form of a loop, or end free.

According to the observations of *Meissner* and *R. Wagner*, nerves are not to be found in all the papillæ of the palm and sole, but only in certain of them which contain a peculiar central structure, called *corpusculum tactus*, and are, for the most part, also destitute of vessels. This assertion is, upon the whole, right; and the papillæ may be divided into vascular and nervous. With regard to the nature of the tactile corpuscles (fig. 37), microscopists entertain different views. I am of opinion that they are composed of an axial tract of homogeneous connective tissue and an external layer of fusiform plasm-cells, and I cannot, therefore, recognise a special structure in them. Nerves pass into the papillæ containing tactile corpuscles to the number of one, two, or four, run on the external surface of the corpuscles, either straight or in a spiral manner, to the summit, and end sometimes apparently *free*, sometimes in *loops*, although it cannot be affirmed that these loops are the true terminations. *Papillæ*, with the so-called tactile corpuscles, have been hitherto found, in addition to the places mentioned above, more sparingly and less developed on the red border of the lip, on the tip of the tongue, on the nipple, the *glans penis*, and the *clitoris*.

In the hand, these so-named tactile corpuscles are almost wholly confined to the palmar surface; they are found especially on the fingers, particularly the third segment. On the foot, they are likewise seated, for the most part, on the extremities of the third phalanges of the toes; still they are not entirely wanting in the middle of the sole, or even on the heel. On the dorsal surface of the hands and feet a few such bodies are often found; sometimes they are wanting. With regard to their number, *Meissner* counted, on the terminal phalanx of the index-finger of a man, 400 papillæ in a square line, of which 108, or one-fourth, possessed tactile bodies. In a square line of the second phalanx 40 bodies were found; on the metacarpal phalanx, 15; on the skin over the metacarpal bone of the little finger, 8; on the plantar surface of the terminal phalanx of the great toe, 34; in the centre of

Fig. 37.

A. Side view of a papilla of the hand. *a*. Cortical layer, with plasm-cells and fine elastic fibres; *b*. tactile corpuscle, with transverse nuclei; *c*. small nerve of the papilla, with neurilemma; *d*. its two nervous fibres running with spiral coils around the tactile corpuscle; *e*. apparent termination of one of these fibres. B. A tactile papilla seen from above, so as to show its transverse section *a*. Cortical layer, with plasm-cells; *b*. a nerve-fibre; *c*. outer layer of the tactile body, with nuclei; *d*. clear interior substance. From the human subject; treated with acetic acid. Magnified 350 times.

the sole of the foot, 7 to 8. With respect to their size, *Meissner* found those on the palm $\frac{1}{18}'''$—$\frac{1}{31}'''$—$\frac{1}{73}'''$ long, and $\frac{1}{22}'''$—$\frac{1}{40}'''$ broad; those of the dorsal surface of the fingers, $1'''$—$\frac{1}{72}'''$ in length and breadth; those on the heel, $\frac{1}{30}'''$—$\frac{1}{83}'''$ in length and breadth.

In the hand, the *corpuscula tactus* are seen more especially in the compound papillæ, in peculiar, more or less distinct, mostly short, but often longer points; more seldom, they occur in simple *papillæ*.

Frequently, especially after the addition of acetic acid, they present here and there constrictions, and sometimes a spiral form, so that they often come to have a certain resemblance to a bundle of areolar tissue treated in the same manner, or to a spiral sudoriparous duct. In other places, the papillæ contain no tactile bodies and no nerves, and the manner in which the latter terminate is entirely unknown.

The elements of the nerves of the skin do not present any special peculiarities. In the small nerve-trunks, in the subcutaneous cellular tissue, some of the fibres measure as much as 0·005''' and 0·006''', which is also the case in the deepest portions of the corium; while towards the surface they all become gradually finer. In the terminal plexuses, I find they vary in different localities from 0·003''' to 0·0016'''; lastly, in the papillæ, from 0·0008''' to 0·002'''.

§ 40. *Development of the Cutis.*—The following may be considered as an outline of the development of the cutis in the fœtus: The corium consists, at first, of cells, which, although not in man, may in animals (*e.g.* the frog) be traced back to the first formative cells of the embryo. A large portion of these cells are converted into connective tissue, becoming spindle-shaped, blending together, and being metamorphosed into bundles of fibrils. This process, to all appearance, takes place first in the *fascia superficialis* and the subcutaneous cellular tissue; next in the reticular, and lastly, in the papillary part of the corium. Another portion of the cells are changed into vessels and nerves, as can be followed to some extent in man, and very beautifully in the batrachia (see my memoir in *Ann. d. Sc. Nat.*, 1846); a third part, finally, are converted into elastic fibres and plasm-cells, and by the formation of fat in their interior, into fat-cells (see above). When the first foundation of all these parts has been laid, they increase in a manner which is not yet in all points ascertained. The corium grows evidently from within outwards (so that the papillæ are the last to be formed), partly by the growth of its original elements, partly through means of cells, which possibly proceed from the original formative cells. The panniculus adiposus increases, likewise, partly by the enlargement of its primitive cells, partly by the formation of others, as also of connective tissue and vessels. In this way, the skin continues to grow for a long time after birth (thus in children the corium is, according to *Krause*, only half as thick as in the adult), till at length, but at a time as yet undetermined, the new formation of cells ceases, and also, at a much later period, the extension of the already-formed elements, cells, fibres, etc. The fat-cells, in which the process of growth is especially perceptible, are, according to *Harting*, in adults, in the cavity of the orbit twice, in the palmar surface of the hand three times the size of those in the new-born child; whence it follows that they enlarge in proportion to the parts of the body to which they belong.

The skin, in embryos two months old, is 0·006‴ to 0·01‴ thick, and entirely made up of cells. In the third month, it amounts to 0·06‴, and already possesses tolerably evident connective tissue. In the fourth month, the first fat-lobules arise, together with the ridges on the hand and sole of the foot. In the sixth month, the skin measures 0·6‴ to 0·7‴, and the *papillæ* become developed. From the seventh month onwards, the panniculus adiposus is very much increased, and is, at birth, relatively thicker than in the adult.

§ 41. *Physiological Remarks.*—When we endeavour to bring the anatomical data, communicated above, into unison with the phenomena of sensation of the skin, we encounter very considerable difficulties. The more minute anatomy of the skin, as at present known, fails to demonstrate nerves in all the papillæ, or even in the majority of them; and, nevertheless, experiment shows that all parts of the skin are sensitive, although not with equal acuteness. As the papillæ which contain nerves are but scanty in the palm of the hand, and in other places very rare, or even not to be demonstrated, we are obliged either to lay down the hypothesis, that all papillæ contain nerve-tubules destitute of white substance, or to have recourse to the nervous plexuses at the bases of the papillæ. I must, for the present, prefer the latter explanation, although these plexuses are, in many places, so scanty, that it appears almost impossible, by means of them, to explain the fact, that the slightest contact of the epidermis produces sensation. If we are not in a position to explain how every part of the skin is sensitive, we are still less able to offer an explanation of the various kinds of sensations. Nevertheless, the following considerations may be stated as to the latter question:

The stimulation of the extremities of the nerves in the most external parts of the cutis takes place either directly or indirectly. The former, such, for example, as is caused in a denuded part of the cutis by a penetrating instrument, stimulating fluids, etc., is much more intense than that effected through the medium of the cuticle, as this covering serves as a protection against too strong impressions, and moderates their influence according to its greater or less development. Now it can be partly explained anatomically, why the fineness and vividness of the sense of touch is not everywhere the same; less on the hairy scalp, the back, and the two upper segments of the extremities, than on the face, the genitals, the hand and foot, chest, and abdomen. Firstly, the epidermis is thin where the sensibility is great, as upon the eyelids and the face, or has, at least, a thin horny layer, as upon the *penis* and *clitoris;* whilst, upon the back and extremities, it is, in part considerably thicker. But this circumstance alone does not suffice to explain all, as parts endowed with a thicker epidermis, such as the palm of the hand and sole of the foot, are capable of fine and delicate impressions, nay, more so than others with a thinner covering, as the dorsal surfaces of the hands and feet. Another circumstance must here manifestly be taken into account, namely, that *the different parts of the skin are not equally supplied with nerves.* Simple inspection shows, that the nerves upon the palm of the hand and sole of the foot are more numerous than on the dorsal surface of these organs; upon the *glans penis* and *clitoris*, the nipple, the face, they are more numerous than upon the abdomen, back, thighs, etc.; and my measurements of the sensitive roots of the spinal nerves confirm this in part. Again, the number of the distinctly demonstrable dark-contoured nerve-fibres in the papillæ and superficial plexus is also connected with that of the nerves, for nowhere is this more considerable than on the tips of the fingers, the lips, the apex of the tongue, and the *glans penis.*

E. H. Weber has endeavoured to prove, in his last excellent paper on the sense of touch, that only the terminations of the nerves in the skin, and not the fibres in the nervous trunks, constitute the media of the sensations of pressure, warmth, and cold; and, therefore, thinks it probable that minute organs of touch, hitherto unknown, may be present in the skin. *R. Wagner* believes, in fact, that *Meissner* and he have found these organs in the so-called tactile bodies; and has expressed the opinion that these organs, which he believes are composed of membranes arranged in layers, and in whose interstices there is a very small quantity of fluid, are, like elastic cushions, or a bladder filled with fluid, very well adapted to receive impressions from the epidermis at their point which is directed towards the surface, and to propagate them to the nervous extremities which lie in and upon these bodies.

In my opinion, *Weber's* view of the greater sensibility of the terminations of the nerves can scarcely be doubted; on the other hand, there is no reason to be perceived, *à priori*, why, in order to render it available, peculiar and as yet unknown organs should be required; nor why the conditions already mentioned by me, the more *isolated course* of the nerve tubules in the papillæ and terminal plexuses, their *fineness*, *superficial position*, and the *delicacy* or *absence* of the *neurilemma*, do not completely suffice as an explanation. At all events, it is easy to show that the tactile bodies of *Meissner* and *Wagner* are not tactile organs, in the sense intended by *Weber*. Apart from the circumstance, that *Wagner's* account of their structure is incorrect, we find *that all the essential functions of the skin can also be fulfilled without such bodies.* The sensation of warmth and cold, of tickling, of pressure, of pricking, of burning, or of pain, takes place in the entire extent of the skin, and in parts where such bodies are decidedly wanting, which sufficiently shows *that they have not, in the remotest degree,* the importance which has been ascribed to them by *Wagner*. Nevertheless, it is plainly not without some reason that they are situated in places in which the sensibility to pressure is the most delicate, and which we use prominently as organs of touch, as on the extremities of the fingers, the tip of the tongue, and the margins of the lips; and I regard them as parts, *which, by virtue of their composition, which consists principally of dense, immature connective and elastic tissue, impart a certain firmness to the apices of the papillæ, and serve as a firmer support to the nerves;* whence it arises, that a pressure, which in other places is not sufficient to compress the nerves, here operates. They are, accordingly, to be regarded as organs like the phalangeal bones and the nails, not essential and absolutely necessary to the sensation of pressure and touch, but only capable of rendering the function more acute than in other parts. If, in this sense, they are designated tactile bodies, I have nothing to object, only then the phalanges and the nails, and the 'whiskers' of quadrupeds, may be with the same propriety called tactile organs.

The *contractility* of the skin shows itself in the wrinkling of the scrotum and of the skin of the penis, the erection of the nipple, and the occurrence of the so-called goose-skin, *cutis anserina*. This depends upon the above-described smooth muscles of the skin, which, as *Froriep*, and afterwards *Brown-Séquard* and I have found, contract under the influence of electricity; for even in the living subject the cutis anserina and erection of the nipple, and in the bodies of executed persons a wrinkling of the *scrotum*, can be effected by that stimulus. During the erection of the nipple by means of gentle mechanical stimulation, the entire *areola* diminishes by the contraction of its circular fibres, and thus pushes forwards the nipple itself, whose fibres, in this case, appear to be relaxed. Under the influence of cold the nipple and its areola contract, and both become small and hard. The *cutis anserina*, which consists in local contractions of those parts of the skin seated around the hair-follicles, by which the openings of the follicles are pushed forwards conically, can be easily explained by means of the muscles found by me, which extend from the superficial parts of the *corium* downwards to the hair-follicles, and when they are in activity, protrude the follicles, and draw in those parts from which they take their origin. The assumption of a contractile connective tissue in the skin, as also in other parts, I must, as formerly (*Mittheil. der Zürcher Naturf. Gesellschaft*, 1847), decidedly reject, because the existence of smooth muscles, demonstrable by the microscope in the skin, whose contraction under the influence of galvanism can be shown by experiment, sufficiently explains all the phenomena of contraction exhibited by the skin.

With reference to the office of the touch-bodies, *Meissner* has, in his larger work, expressed the opinion, that they are subservient to a specific function, which is only met with in the hands and feet, *that of the simple sensation of touch*. This is defined as the simple perception of an external object, without the sensation of pressure; but in a later work (*Zeitschrift f. rat. Med.*, 1854, page 260), is designated as 'Perception of pressure by means of the touch-bodies.' No one will blame the able discoverer of the touch-bodies, in endeavouring to ascribe to them an important physiological function; but, upon the other hand, no unprejudiced person will be induced to declare the perceptions of pressure, which we experience in the palm and sole (apart from their delicacy), to be different from those which we receive from other nerves of the skin.

B. EPIDERMIS.

§ 42. The corium is, in its entire extent, covered by a semi-transparent membrane, which is destitute of vessels and nerves, and composed entirely of cells — the *epidermis*. This is closely fitted to all the subjacent elevations and depressions; and on this account its inner surface is an exact mould of the external surface of the corium, and in such a manner, that where the latter presents an elevation, the former exhibits a conformable depression, and *vice versâ*. Upon the external surface, also, of the epidermis, the form of the *corium* is repeated, to a certain extent, inasmuch as the more important elevations and depressions, such as the ridges

Fig. 38.

Under surface of the epidermis, detached by maceration from the palm, showing the double rows of depressions, in which the papillæ have been lodged, with the sudoriferous ducts extracted out of the cutis. After Todd and Bowman.

of the palm of the hand and of the sole of the foot, the furrows at the joints, the muscular insertions, etc., are expressed on it — the latter even more strongly; while the *papillæ* occasion either no discernible elevation, or scarcely any.

The epidermis is composed of two layers, which differ from each other in structure and chemical composition, and are separated by a tolerably distinct boundary line, viz., the *mucous layer* and the *horny layer*.

§ 43. The *mucous layer*, *stratum Malpighii*, *rete*, or *mucus Malpighii* of many authors, is the inner undulating portion of the epidermis, immediately adjoining the *corium*, which in many places, even with the naked eye, can be distinguished by its white or various shades of brown colour from the horny layer, and is characterised by its soft, easily destructible, peculiarly arranged, small cells.

The form of these cells, as well as their arrangement, is not everywhere the same. The most internal, which lie immediately upon the free surface of the corium in the form of a simple layer, without intermingled nuclei or semi-fluid substance, are elongated, like columnar epithelial cells, and stand perpendicularly on the *corium*; their length amounts to from 0·0033‴ to 0·006‴, their breadth, 0·0025‴ to 0·003‴.

Fig. 39.

Perpendicular section through the skin of a negro (from the leg). *a.* Papillæ; *b.* deepest intensely coloured layer of elongated cells of the stratum mucosum; *c.* upper layer of the stratum mucosum; *d.* horny layer. Magnified 150 diameters.

Upon these immediately follow, in most regions, oblong or even round cells, from 0·003‴ to 0·004‴, in several layers; but in some places, as on the hand and foot, at the free border of the eye-lids, on the mucous layer of the nails and hair, one, two, and even three layers of likewise elongated and perpendicularly arranged elements, are interposed between the round and the elongated cells, so that the mucous layer, on account of the numerous perpendicularly disposed layers of cells, presents, under a higher magnifying power, a striated appearance. This condition is the more conspicuous, since the other elements of the mucous layer, the further they are traced from the first round cells outwardly, become thinner in another direction, viz., are flattened horizontally; and, at length, in the uppermost layers, are converted into vesicles, from 0·006‴ to 0·016‴ in breadth, and from 0·002‴ to 0·008‴ in thickness. At the same time, in consequence of mutual pressure, they take on a more or less evident *polygonal* form, which can also be perceived in isolated cells.

All the cells of the mucous layer agree essentially in their structure, and are nucleated vesicles entirely filled with fluid. Their membrane is pale, in the smallest often difficult to demonstrate, often quite evident, always delicate, and though stouter in the larger cells, yet not to be compared to that of the cells of the horny layer. Their contents are never entirely fluid, although, with the exception of coloured epidermis (see below), they never normally contain large elements, such as coarse granules, or oil-drops, for instance, but a finely granulated matter, in which the granules are more or less distinct; and these granules, without exception, become more scanty in the more external cells. The nucleus is small in the smallest cells (0·0013‴ to 0·0025‴); in the large, larger (0·003‴ to 0·005‴); spherical or lenticular in the round and flattened, oblong in the elongated cells. In the larger cells it appears distinctly as a vesicle, often with a nucleolus, and lies in the centre amidst the contents; in the smaller, it is, to all appearance, more granular or homogeneous, without a perceptible nucleolus, and so situated, that it not unfrequently touches the cell-wall.

The cells of the mucous layer become pale in dilute caustic alkalies, swell, and soon dissolve (the deepest layers first) into a mucous mass. Acetic acid acts upon these cells much less powerfully, and is especially suitable for their examination.

§ 44. The horny layer, *stratum corneum*, constitutes the external semi-transparent portion of the epidermis, which, in the white races, is colourless, and consists almost entirely of uniformly constructed cells converted into plates. The deepest still very much resemble the most superficial cells of the mucous layer; but even in the second or third layer, the widely deviating epidermic or horny plates are to be found. They are real plates of middling thickness, which, in the lower and middle portions of the horny layer, possess a tolerably regular, polygonal form, and smooth surfaces; in the upper layers, on the other hand, their outline becomes more irregular, and they are variously curved and bent, and, therefore, often appear wrinkled and folded. These plates must be considered as completely flattened cells, furnished with a very small quantity of a viscid fluid, and not as homogeneous lamellæ, formed entirely of the same substance, as might appear at first sight; for on the addition of various re-agents, particularly of acetic acid or caustic potass and soda, they swell and acquire the form of

Fig. 40.

Horny plates of man. 1. Without addition, viewed from the surface; 2 and 3. treated with water, granular and dark; 4. nucleated plates, such as occur on the outer surface of the labia minora, and on the glans penis. Magnified 350 diameters vesicles. After this, a rudimentary nucleus comes into view in a few of them, but by no means in the majority, and particularly in those from the middle and inner portions of the horny layer. The nucleus has the form of a flat, homogeneous, roundish or elongated corpuscle, from 0·003''' to 0·004''' long, and 0·002''' to 0·003''' broad; and, on account of its dark contour, is easily perceived, especially when viewed from the side. The size of the plates of the ordinary horny layer varies from 0·008''' to 0·020''', and generally measures 0·010''' to 0·016'''.

Whilst the mucous layer, the uppermost cells excepted, is only indistinctly stratified, an evident *stratification* is found throughout the horny layer, occasioned by the apposition of the surfaces of the plates, which, according to the thickness of the whole, form a variable number of strata, having, in the inner layers, an undulating course. These strata, however, are not capable of being separated from each other as simple layers of cells, but cohere by their contiguous surfaces in such a way that they are separable with the knife only into portions composed of several simple strata; and, as such, they can be readily shown, especially after boiling or maceration of the epidermis.

§ 45. With respect to the *colour* of the epidermis, the horny layer is, as has been already mentioned, in the white races, transparent and colourless, or has a slight tinge of yellow; the mucous layer, yellowish-white, or with various shades of brown or blackish-brown. The darker pigment, which is found on the areola of the nipple, on the genitals, and, in exceptional cases, also, in other parts of the skin, is not situated in *special* pigment-cells, but in the ordinary cells of the mucous layer, around whose nuclei either a finely granular or more homogeneous colouring matter, or actual pigment-granules, are deposited. Sometimes the deepest layer of these cells is alone coloured, sometimes two, three, or more layers, so that the deep part appears as a dark stratum. In the negro and the other coloured races of mankind, the epidermis is likewise the only part which is coloured, while the corium presents entirely the same characters as in the European; the pigment, however, is much darker and more widely distributed. All the cells of the mucous layer are, with the exception of their membranes, coloured in their entire extent, and more especially in the parts surrounding the nucleus, which, in the deeper strata, are by far the darkest parts of the cells. The horny layer, also, has a yellowish or brownish tinge.

Pathological colourings of the epidermis (freckles, mother's marks, etc.), according to *Simon*, *Krause*, *Bärensprung*, and what I myself have seen, present entirely the same characters as the more intensely coloured parts in the white races, and the skin of the negro. Different from these are the pigments in the *corium* and the *papillæ*, which are observed in cicatrices after chronic inflammation of the skin,—and often, as in *Ichthyosis* and many *nævi*, in conjunction with a coloured epidermis,—in which the pigment is developed directly from the blood-corpuscles and their colouring matter. Cases of partially or totally white negroes and black Europeans, not in consequence of a change of the climate, but from a congenital or subsequently occurring abnormal condition of the skin, have been recorded (see HILDEBRANDT-WEBER, ii., page 526, FLOURENS, *Compt. rend.*, xvii.); still, in respect to future cases of this kind, at least in the dark coloration of Europeans, it must be kept in mind, that it can also arise from deposited colouring matter of the bile.

§ 46. *The thickness of the entire epidermis* varies between $\frac{1}{75}'''$ and $1\frac{2}{5}'''$, which depends upon the various depths of the horny layer, and measures in most places between $\frac{1}{50}'''$ and $\frac{1}{10}'''$.

The absolute thickness of the *mucous layer* (at the base of the papillæ) varies between 0·007''' and 0·16'''; in many places, as in the face, the genitals, and on the breasts, it is thicker than the horny layer, and measures 0·04''', or where it is thinner, from 0·01''' to 0·02'''. The horny layer measures only 0·005''' in many places, in others attains the thickness of 1''' or more; where it exceeds the mucous layer, it amounts to 0·1''' to 0·4'''; where it is less than it, 0·01'''.

§ 47. *Physical and Chemical Qualities.*—The cells of the epidermis do not contain, either in their membranes or in their interstices, demonstrable pores (apart from the sudoriparous canals and hair-follicles, which, in a certain measure, have their outermost parts excavated in the epidermis), and form a very firm, scarcely permeable mass. Many experiments, particularly those of *Krause*, show that the horny layer of the epidermis does not allow liquids to permeate it (except such as act chemically on the structure, as mineral acids and caustic alkalies), either by pores, imbibition, or endosmose and exosmose, but takes up with facility gaseous and volatile substances (alcohol, ether, acetic acid, ammonia, ethereal solutions of chloride of iron, alcoholic solutions of acetate of lead, etc.), or gives them off (cutaneous transpiration). And this conclusion is not weakened by the undeniable passage of water and other liquids, unguents, and even solid bodies (sulphur, vermilion) through the uninjured epidermis; for, in these cases absorption is favoured by mechanical *intrusion* of the substances in and through the sudoriparous canals and hair-follicles, or their penetration into the sudoriparous canals and mixture with the sweat. The mucous layer, at all events, is easily permeated by liquids, as pathological anatomy sufficiently shows (exudations, which permeate the mucous layer, and raise up the epidermis in the form of vesicles; easy absorption after the horny layer and uppermost strata of the mucous layer are removed by vesication).

The so-called *keratine*, which constitutes the membranes of the horny plates, is insoluble in water, easily soluble in concentrated alkalies and concentrated sulphuric acid; acetic acid also dissolves it, after it has first become gelatinous, whereby it is distinguished from the protein substance of the hair. It contains less sulphur than that of the hair and nails, which may be the cause that salts of lead, quicksilver, and bismuth colour the hair, but not the epidermis. Besides, there is, according to *Mulder*, a jelly-like matter in the horny layer, which is obtained by boiling in water, and is said to yield gelatine.

§ 48. *Growth and Regeneration.*—The epidermis possesses no continuous growth dependent on intrinsic causes, and founded on the vital relations of its cells, or of the corium; it is essentially a stable structure, which does not vary in its elementary parts, but, like a cartilage, directs all its vital energies to maintain itself as a whole (constant thickness of the entire epidermis and relation of the *rete Malpighii* to the horny layer), and, in its individual parts, always the same. Since, however, the removal of the most external layers, if not necessarily, still accidentally, occurs more or less over the entire body, the epidermis is continually undergoing repair of its lost substance, or, in other words, *growing*; its vegetative life is thus manifested in a more perceptible manner. In either case, however, the fluids requisite for the epidermis are derived from the corium and its vessels. We may assume that in every place a certain fixed quantity of plasma, corresponding to anatomical and physiological conditions of the vessels of the *cutis* and the thickness of the epidermis, penetrates the latter; and, except as regards the more watery portion, destined for the formation of the cutaneous transpiration, when the epidermis is not growing, simply fills its cells and plates, preserves their vital power, and, at most, causes at times more abundant collections of pigment in the *rete Malpighii*. If, on the other hand, the external layers are removed, a certain quantity of *plasma* becomes free and appropriable, and their regeneration takes place, which, if it steadily continues, may be called growth. The deepest layers of cells are undoubtedly concerned in this regeneration, in forming new cells by often repeated divisions.

In the deep fold of the skin which surrounds the *glans penis* and the *clitoris*, a constant throwing off and reproduction of the epidermic scales, which are here soft and nucleated, takes place, by which a peculiar secretion, the *smegma præputii*, is occasioned, in the formation of which, at least in the male sex, the secretion of the sebaceous follicles of the prepuce (see *postea*) takes part. A casting-off, or desquamation of the entire horny layer of the epidermis in a more extensive degree, as occurs in the embryo and in many animals, is not met with in after life, except in certain diseases. On the other hand, its capability of regeneration is exhibited in other ways besides that above described. When portions of the epidermis are cut out, they are easily and speedily restored, provided the corium is not injured. This does not take place by means of the deposition of epidermis immediately from the corium in the seat of the wound, but by an up-growth of the whole epidermis from below; and this undoubtedly does not take place by a new formation of cells, but by the increase of the remaining cells of the Malpighian layer, probably by means of cell-division. If the corium be injured as well, an epidermis is formed upon the substance of the cicatrix, but without the original depressions and elevations, because the new cutis possesses no papillæ or ridges. If the epidermis be raised into vesicles by means of certain irritating substances, as tartrate of antimony, or by scorching, scalding, etc., the raised portion, which consists of the horny layer and part of the mucous layer, never again becomes attached; but a new horny layer is gradually formed from the main portion of the mucous layer, which generally remains adherent to the papillæ.

§ 49. *Development of the Epidermis.*—The first layers of the epidermis arise, in the mammalia, from the metamorphosis of the most superficial formative cells which originally compose the young embryo. When the first foundations of the mucous and horny layers are laid down, the former continually increases in thickness by the multiplication of its elements; while the horny layer recruits itself therefrom, in order to its own increase and the repair of loss by desquamation, just in the same manner as in the adult. As regards the horizontal extension of the epidermis, it would seem to be, only in a very slight degree, owing to the enlargement of the elements, as HARTING (*Recherches Micrometr.*, p. 47) justly infers from the fact, that the epidermic scales of the fœtus and of the adult differ very little in superficial extent. Accordingly, from the great horizontal growth of the *cutis* and *rete Malpighii*, and the small capability of extension of the strata of the horny layer, we are constrained to assume that a series of *desquamations* of the latter occur, which, if this opinion be correct, must be demonstrable after birth.

During embryonic life repeated desquamations of the epidermis take place. This can be demonstrated with ease in the second half of intra-uterine life, when the process is very energetic. From the fifth month onwards, especially, the casting off of the outermost epidermic cells continues in an increasing degree; and as they become in most places intermingled with the sebaceous matter of the skin, which begins to be excreted at this period, they form the so-called *smegma embryonum*, or *vernix caseosa*. This is a whitish or yellowish, inodorous, greasy substance, which, especially from the sixth month onwards, covers the entire surface of the fœtus with a considerably thick, or even stratified coating. It is found in large quantities on the genitals, the flexion-side of the joints (axilla, knee, inguinal region), the sole of the foot, the palm of the hand, the back, ear, and head. Microscopically examined, it is seen to consist principally of epidermis-cells, with cells from the sebaceous follicles and globules of fat. Two or three days after birth, the smegma is thrown off and the permanent epidermis makes its appearance, the further changes of which are but little known. In the child of four months of age, the epidermis is disproportionally thick, which especially depends upon the mucous layer, whilst the horny layer is only slightly developed. The pigment of the mucous layer, as well in the coloured races as in Europeans, is developed after birth; but in the former (the negro) the margins of the nails, the areola of the nipple, and the genital organs become coloured about the third day, and on the fifth and sixth day the colour is diffused over the whole body.

In *examining* the skin, perpendicular and horizontal sections of fresh, dried or boiled preparations, moistened with an inactive fluid, or with various agents, as acetic acid and alkalies, are of service. The most important effects of these re-agents have been already mentioned in their proper place. The epidermis can be separated from the corium, easily and in large patches, by maceration or boiling; and, when it is not thick (on the genitals, for instance), also by acetic acid and soda, so that its lower surface and the papillæ of the corium are exhibited most beautifully, and the latter can be investigated isolated or in groups. In the fresh skin, their position and number can be quickly and easily ascertained in horizontal sections, carried through the papillæ and the deep layers of the epidermis. The *vessels* may be studied in thin parts of the skin (genitals and lips) in the fresh condition, or in injected preparations. The *nerves* may be examined in perpendicular sections, in isolated papillæ, or in thin parts of the skin (præputium, glans, eye-lids, or conjunctiva bulbi), after addition of acetic acid and diluted soda, or according to *Gerber's* and *Krause's* method. *Gerber* boils the skin until it becomes transparent, lays it for a few hours in oil of turpentine until the nerves are white and shining, and then examines them in fine perpendicular lamellæ, made with the double knife. According to *Krause*, the nerves may be seen very well by treating the skin with nitric acid, when the proper degree of action is hit upon. The *elastic tissue* is shown very beautifully by acetic acid, soda, and potass. The *smooth muscles* can be with facility isolated in the *tunica dartos*, with more difficulty in the skin of the penis and areola of the nipple, where the observer must be familiar with them, in order in all cases to discern them with the unaided eye. On the hair-follicles they are to be seen under the microscope, when a follicle, with the sebaceous glands belonging to it, is isolated, particularly after the employment of acetic acid, in the form of small bundles by the side and in front of the sebaceous glands, but best of all and most easily in perpendicular sections of boiled skin (*Henle, Eylandt, Lister*). The investigation of the *fat-cells* is especially instructive in the bodies of lean individuals, in which their membranes and nuclei are easily seen; in other cases, their membranes can be easily demonstrated by removal of the fat with ether, but the nuclei are with difficulty brought into view by this agent; they are, however, discovered occasionally here and there, even in full cells. The *epidermis*, and especially its mucous layer, must be examined fresh, and with acetic acid and diluted caustic soda, in fine perpendicular sections; the horny layer, above all, by the addition of alkalies, in perpendicular and horizontal sections; but its elements also separate from one another after maceration, and, for the practised observer, are cognisable even in fresh preparations, both when seen from the side and from the surface.

Literature of the Skin.—GURLT, in MÜLL. *Arch.*, 1835, p. 399. SIMON, *Ueber die Structur der Warzen und über Pigmentbildung in der Haut*, in MÜLL. *Arch.*, 1840, p. 167. KRAUSE, Article *Haut*, in WAGNER'S *Handw. der Physiol.*, ii. 1844, p. 127. KÖLLIKER, *Zur Entwickelungsgeschichte der äussern Haut*, in *Zeitschrift für Wiss. Zool.*, Bd. ii. p. 67; *Histologische Bemerkungen*, ibid, Bd. ii. p. 118. EYLANDT, *De Musculis Organicis in Cute Humana Obviis*, Dorp. Liv., 1850. J. LISTER, *Obs. on the Muscular Tissue of the Skin*, in *Quart. Journal of Micr. Science*, 1853. On the tactile bodies, see R. WAGNER, in MÜLL. *Arch.*, 1852, p. 493; KÖLLIKER, in *Zeitschr. f. Wiss. Zool.*, iv. p. 1; G. MEISSNER, *Beiträge zur Anatomie und Phys. der Haut*, Leipzig, 1853; DALZELL, in *Monthly Journal*. Drawings are given by BERRES, tab. vi., vii., xxiv.; ARNOLD, *Icon. Org. Sens.*, tab. xi.; TODD and BOWMAN, *Physiol. Anatomy*; HASSALL, tab. xxiv., xxvi.; KÖLLIKER, *Mikr. Anat.*, tab. i.; and ECKER, *Icon. Phys.*, tab. xvii.

II.—OF THE NAILS.

§ 50. The nails, *ungues*, are nothing but *peculiarly metamorphosed parts of the epidermis*, and, like the latter, may be divided into two layers, viz., a soft *mucous layer*, and a *horny layer*, or the nail proper.

The part of the *corium* upon which the nail is situated, the *bed* or *matrix* of the nail, corresponds exactly in form with it, is elongated, quadrangular, arched in the centre, and sloped anteriorly and posteriorly, but especially on the sides. Its anterior and middle portions are exposed, when the nail with the epidermis is removed by maceration, its lateral borders and posterior part, on the other hand, are concealed by a process of the *cutis*, the *wall of the nail*, which is, anteriorly, low and rounded off; posteriorly, well defined and longer; and, in conjunction with the bed of the nail, forms a fold, the *fold of the nail*, which embraces the lateral borders and the posterior part (from 2‴ to 3‴ in extent) of its root.

The bed of the nail presents upon its surface peculiar *ridges*,

Fig. 41.

Transverse section through the body and bed of the nail; magnified eight times. *a.* Bed of the nail, with its ridges (black); *b.* corium of the lateral parts of the wall of the nail; *c.* stratum Malpighii of the same part; *d.* stratum Malpighii of the nail, with its ridges (white); *e.* horny layer on the wall of the nail; *f.* horny layer of the nail, or proper nail substance, with shallow notches upon its under surface.

similar to those on the palm of the hand. They begin at the bottom of the fold of the nail, at the posterior edge of its bed, and run forwards partly straight, partly in gentle curves, proceeding from the middle almost as from a pole. At a distance of $2\frac{1}{2}'''$ to $3\frac{1}{2}'''$ from their origin, they are converted into true *laminæ*, of 0·024‴ to 0·1‴ in depth, which run straight forward, almost to the anterior border of the bed of the nail, and then terminate, as if truncated. The boundary between the ridges and laminæ has the form of a curved line, with the convexity directed forwards, and divides the bed of the nail into two segments, which differ both in colour and size. The posterior smaller section is, in its greater part, covered by the wall of the nail, is paler in colour, and supports the root of the nail, while the anterior larger portion is coloured red, and covered by its body. The ridges and laminæ of the bed of the nail, the number of which varies between 50 and 90, are often beset at their edges with papillæ of 0·008‴ to 0·16‴. The wall of the nail has no ridges upon its inferior surface, and but seldom, here and there, a papilla. The papillæ begin again at its margin, where they are tolerably long, and pass thence to its upper surface, which differs in nothing from the rest of the cutis on the back of the fingers and toes.

The corium of the wall and of the bed of the nail is dense, and contains in its deeper portions very little fat, while the ridges and laminæ, with their papillæ, are rich in fine elastic fibres. The vessels are especially numerous in the anterior segment of the bed of the nail; posteriorly, in the part lying under the root of the nail, and in the wall, they are more sparingly distributed; their capillaries (0·005‴ to 0·008‴) are met with at the edges of the laminæ They also pass into the papillæ at the places where these are more developed, and form single loops. The nerves in the deeper portions are arranged in the same manner as those in the skin, but their terminations are unknown; I, at least, have never found nerves in the laminæ.

In the nail itself, the *root*, the *body*, and the *free border* may be distinguished. The soft root corresponds in its extent to the posterior ridged part of the bed of the nail, and is either entirely concealed in the fold, or a small semi-lunar part of it, the *lunula*, is exposed. The posterior border is sharp, slightly bent upwards, and is the thinnest and most flexible portion of the nail. The hard *body*, which increases in thickness and breadth from behind forwards, lies, for the most part, with its superior surface exposed; its somewhat sharp and thin lateral edges are concealed in the lateral portions of the fold, and its inferior surface is situated upon the anterior segment of the bed of the nail; lastly, the free border is, in cut nails, directed straight forwards.

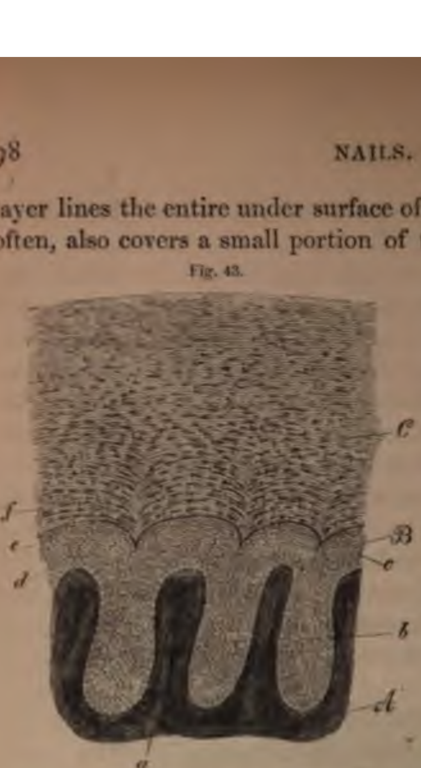
Fig. 42.

Longitudinal section through the middle of the nail and its bed; magnified 8 times. *a*. Bed of the nail, and cutis of the back and point of the finger; *b* mucous layer of the point of the finger; *c*. of the nail; *d*. of the bottom of the fold of the nail; *e*. of the back of the finger; *f*. horny layer of the point of the finger; *g* beginning of it under the edge of the nail; *h*. horny layer of the back of the finger; *i*. termination of it upon the root of the nail; *k*. body; *l*. root; *m*. free edge of the proper substance of the nail.

The inferior surface of the body and of the root of the nail corresponds in form exactly to the bed, and, accordingly, presents laminæ and ridges with intermediate furrows; and as the elevations and depressions mutually lock into each other, the nail is maintained in close connection with the *cutis*, and all the more intimately, from the circumstance that the wall of the nail lies with its under surface upon the lateral borders and the root. The *colour* of the nail is, at its free border, whitish and transparent; in the body, reddish; in the lunula, whitish. When separated from the epidermis and cutis, the nail is rather uniformly white and transparent, but likewise somewhat whiter at the root than in the body.

§ 51. *Structure of the Nail.*—The nail is composed, in its deeper portions, of a soft white *mucous layer*, which is more sharply defined from the hard external horny layer, or proper nail, than are the corresponding layers in the ordinary epidermis. The mucous layer lines the entire under surface of the body and root of the nail, often, also covers a small portion of the upper surface of the root, and alone forms the above-mentioned laminæ on the lower surface of the nail. Its thickness varies from 0·032‴ to 0·26‴.

Fig. 43.



Transverse section through the body of the nail; magnified 250 diameters. A. Cutis of the bed of the nail; B. mucous layer of the nail; C. horny layer of it, or proper nail-substance. *a.* Laminæ of the bed of the nail; *b.* laminæ of the stratum Malpighii of the nail; *c.* ridges of the nail itself; *d.* deepest elongated cells of the mucous layer of the nail; *e.* upper flat-cells of it; *f.* nuclei of the proper substance of the nail.

The mucous layer of the nail consists, like that of the epidermis, entirely of nucleated cells, and agrees with it in all essential points, except that in the deep portions it contains several layers of elongated (0·004‴ to 0·007‴) perpendicular cells, which give rise to a striated appearance. In the negro, and, also, not unfrequently in Europeans, the cells of the mucous layer of the nail contain pigment.

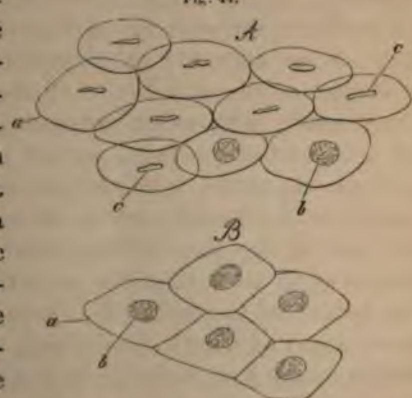
In certain cases, rounded groups of the cells of the mucous layer under the nail are converted into horny plates (*Ammon*), which, even, may lie entirely in the substance of the cutis (*Virchow*); and this has led to the assumption of special follicles under the bed of the nail (*Rainey*).

The horny layer, or the proper nail substance, is the hard and dry part of the nail which forms its free border and upper portion. The under surface posteriorly at the root is even; more anteriorly, it presents sharp ridges separated by broad grooves, which fit into the furrows of the mucous layer of the nail. These ridges of the proper nail substance appear in cross sections, as pointed processes, of 0·01‴ to 0·02‴ in length, which, in general, are most strongly marked at the borders of the nail (0·04‴ to 0·06‴), and correspond exactly in number to the laminæ on the lower surface of the mucous layer. The upper surface of the substance of the nail is, upon the whole, smooth, yet there are often found, even here, parallel, longitudinal streaks or stripes, as the last and nearly effaced indications of the inequalities of its bed.

The thickness of this part of the nail continually increases from the root to near the free border, so that the body is, anteriorly, at least three times thicker (from 0·3‴ to 0·4‴) than the root; and is, at the free border, again somewhat less. Also in its transverse diameter, the substance of the nail is not equally thick throughout, except at the posterior border of the root, but becomes considerably attenuated at the lateral margins, so that the part of the nail which lies in the fold measures no more than 0·06‴ to 0·12‴, and ends with a sharp edge.

The structure of the proper nail-substance is not easily perceived, without the employment of re-agents. In perpendicular sections there are seen, particularly on the body, nothing but horizontal, fine, straight, or curved lines, lying close upon one another, which might be taken for the optical expression of delicate lamellæ; and between these a number of elongated, horizontal streaks, of a dark or peculiar reddish aspect, which are evidently nuclei. At the most posterior portion of the root, and on the lower surface, where it adjoins the mucous layer — and there only — more or less flattened cells, furnished with nuclei and arranged in layers, make their appearance. Horizontal sections show only a pale transparent, here and there granular, substance, for the most part without indication of any kind of structure, at some parts with very indistinct contours of plates, resembling those of the horny layer of the epidermis. Very different appearances, however, are exhibited after treatment with alkalies and mineral acids. By boiling the nail for a short time in dilute caustic soda, or moistening a fine section with this re-agent, all the plates are converted into nucleated cells, of which the deeper are thicker, the superficial more flattened. From these facts, together with what is discoverable in the unaltered nail, it follows that its horny layer consists of closely connected, but not sharply defined, lamellæ; each lamella being made up of one or several layers of nucleated, polygonal, flat scales or plates, which, apart from the nuclei,

Fig. 44.



Nail-plates, boiled with caustic soda; magnified 350 times. A. From the side; B. from the surface. *a*. Membranes of the distended elements; *b*. their nuclei from the surface; *c*. from the side.

resemble very much those of the horny layer of the epidermis, and, in the most inferior layers, are thicker and smaller than in the upper and most superficial. Those of 0·012‴ to 0·016‴ may be considered as of a medium size,—such as are seen on the addition of sulphuric acid, which otherwise has but little action, and at the commencement of the action of potass and soda.

§ 52. With regard to the *relation of the nail to the epidermis*, I refer especially to the perpendicular and transverse sections given in figs. 40 and 43. They show, in the first place, that the epidermis lies upon the root, the posterior part of the body, and the borders of the nail, and is connected with it under the free border and on the anterior portions of the lateral margins. That is, whilst the mucous layer of the epidermis passes continuously, and without any boundary line, into that of the nail, the horny layer is never properly continued immediately into the true substance of the nail, but partly lies with its lamellæ parallel to it, partly meets it at various oblique angles. At the root, the horny layer of the epidermis extends more or less deeply into the fold of the nail, and may here reach back to the posterior border of the root; it advances, also, as a thin layer towards the termination of the lunula, or the commencement of the body, where it becomes very fine. In this situation, the cells are, anteriorly and posteriorly, placed parallel to the surface of the nail; but in the middle, where the nail is thickest, they are set obliquely or perpendicularly upon it. The relation is similar at the free border of the nail, where the horny layer abuts, partly with more horizontal, partly with oblique lamellæ, upon the end of the lower surface of the body of the nail, and is, perhaps, continued upon the commencement of its free border. Lastly, on the lateral borders, the horny layer anteriorly lies under the nail in the form of horizontal layers, and, more posteriorly, presents the same relations as at the root, or is simply applied to the border of the nail. The horny layer of the epidermis thus forms a sort of sheath for the nail, which somewhat resembles the sheath of the hair, although it is much more incomplete. If we compare the nail with the epidermis, we find, in the structure of its mucous layer, no peculiarity of any consequence; but it is different with the horny layer, which is distinguished from the epidermis by its more consistent, more flattened, and intimately coherent as well as nucleated cells, which are also chemically different. Nevertheless, the agreement of the latter structure is so great, that the proper nail may be, as, indeed, it has long been, would appear, indeed, as *Pechlin* relates, that such a regeneration can take place periodically, inasmuch as a boy every autumn lost his nails, which first became dark blue, together with the epidermis (horny layer?), and they were subsequently reproduced. In such a case, the entire bed of the nail, according to *Lauth* and *Hyrtl*, becomes covered with soft horny plates, which gradually harden, and are transformed into a real nail, which finally projects with its free border over the point of the finger. After loss of the distal phalanx of the finger, rudimentary nails are, in many cases, developed on the dorsal surface of the second, and even on that of the proximal phalanx. As the formation of the substance of the nail depends upon the vessels of its bed, we may, with *Henle*, assume, that varying conditions of the latter may often occasion an irregular growth, in some places thickening, in others thinning of the nail, and even its entire detachment; and that the deformities of the nails in cyanosis and phthisis also depend upon this. Very frequently, however, as I have observed, the thickening and malformation proceed from partial impermeability of the capillaries of the bed of the nail. After section of the *nervus ischiadicus* in rabbits, *Steinrück* observed a shedding of the hair and nails, which is to be ascribed to the influence of the nerves upon the vessels. Lastly, the shape of the bed of the nail also influences its formation. It is thus explained how, after inflammation and closure of the fold of the nail, the formation of new nail at the posterior border ceases, so that the nail does not grow forwards any more, but remains covering its bed and closely applied to it at its borders (see *Henle*, *l.c.*). *Meissner*, and especially *Virchow*, have described many cases of cryptogamic productions (*fungi*) in the nails.

§ 54. The *development* of the nail begins in the third month of intra-uterine life with the formation of the bed and the fold, which are marked off from the other parts by the gradual growth of skin into the wall of the nail. The bed of the nail is, at first, covered by the same cells which, in other parts, form the epidermis, except that by the third month the cells of the mucous layer are already characterised by their elongated and polygonal shape (length, 0·004‴; breadth, 0·001‴ to 0·0016‴). In the fourth month, there appears between the mucous and horny layers of the epidermis on the bed of the nail,—the latter of which is formed by a single stratum of polygonal, distinctly nucleated cells,—an intermediate layer of pale, flat, likewise polygonal and nucleated, cells, 0·009‴ in diameter, which are firmly connected with each other, and may be considered as the first indication of the proper nail-substance. At the same time, the stratum Malpighii under these cells becomes thickened, so that it is decidedly composed of, at least, two layers. The nail, accordingly, is *at first entirely enclosed within the epidermis*, it is formed *over the whole surface of the bed of the nail*, in the shape of a quadrangular plate, and arises between the embryonic mucous layer and horny layer, undoubtedly by a transformation of the cells of the mucous layer. During its further development, the nail is thickened by the addition of new cells from below, and is enlarged by the extension of its elements and addition of new cells at its margins; but it remains concealed under the horny layer of the epidermis, even to the end of the fifth month, till at last it becomes free, and, in the seventh month, even begins to grow longitudinally, so that at this time, except in its greater softness and different dimensions, it differs in no essential point from the full-grown nail. In the new-born child, the nail is, in the body, 0·3‴ to 0·4‴ thick, with a free border projecting 2 lines, and consists of elongated, polygonal, nucleated plates, of 0·02‴ to 0·028‴.

Soon after birth, the free border of the nail, which evidently is nothing but the nail of the six-months' fœtus which has been pushed forwards, is thrown off at least once, or, according to *Weber*, several times. In the sixth and seventh months after birth, the nails with which the child is born, are, as I find, wholly replaced by new ones; and, in the second and third year, the plates of the nails differ in nothing from those of the adult, whence it results, that the nail is enlarged and thickened, less from enlargement of its elements, than by the addition of new ones at its borders and from below.

In the *examination* of the cells and plates of the nail, fine sections of fresh nails are particularly serviceable, either simply or with the addition of reagents, and, above all, of soda and sulphuric acid, which cause the plates of the nail to swell up. In order to make out the relations of the individual parts of the nail to each other and to the epidermis, the nail and cutis must be separated by maceration or boiling in water. The nail is thus detached, along with the epidermis, from the finger, and the mode of its connection can be recognised in transverse and longitudinal sections. Also the bed of the nail, with its laminæ and ridges, the fold of the nail and the laminæ of the mucous layer of the nail, come easily into view in this way.

As fine sections in such nails are, in the most important places, the root and margin, not easily made, it is also necessary to use recent specimens, also nails which have been detached with the cutis from the bone and dried, which then furnish all information that could be desired, inasmuch as segments of such nails easily swell up in water, and by the action of acetic acid or soda, so that the structure of their various layers becomes very distinct.

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III.—Of the Hairs.

§ 55. In every hair we distinguish the free portion, *shaft* (*scapus*), with its attenuated point, from the part enclosed within the follicle, the *root* (*radix*). The former is, in general, straight and cylindrical in straight hair; in curling hair, flexuous, and somewhat flattened; in frizzly and woolly hair, it is spirally twisted, and quite flat or slightly ribbed. The root is always straight, nearly cylindrical, and, at least in its lower part, softer and thicker than the shaft; in vigorous hairs it terminates in a still softer knob-shaped swelling, from 1½ to 3 times thicker than the shaft—the *hair-bulb* (*bulbus pili*),—which is placed like a cap upon a papilliform process of the follicle, the *hair-papilla*, or, in other terms, receives the latter into an excavation in its base.

Fig.

Hair and hair-follicle, of middling size: magnified 50 times. *a.* Shaft; *b.* root; *c.* bulb; *d.* epidermis of the hair; *e.* inner root-sheath; *f.* outer root-sheath; *g.* structureless membrane of the hair-follicle; *h.* transverse and longitudinal fibrous layer of the same; *i.* papilla of the hair-follicle; *k.* excretory ducts of two sebaceous glands; *l.* cutis; *m.* mucous; and *n.* horny layer of the epidermis, the latter entering a certain way into the follicle; *o.* end of the inner root-sheath.

§ 56. *Distribution and Size of the Hairs.*—With regard to size, three varieties may be recognised: 1. long soft hairs, from 1 to 3 feet and more in length, and 0·02‴ to 0·05‴ in thickness: 2. short, stiff, thick hairs, of ¼ to ½ an inch long, and 0·03‴ to 0·07‴ thick; 3. short, extremely fine hairs, downy hair (*Lanugo*), of 1‴ to 6‴ long, and 0·006‴ to 0·01‴ thick. The distribution of the first form is well known; to the second form belong the hairs at the entrance of the nostrils (*vibrissæ*), and in the external auditory meatus, the eyelashes (*cilia*) and those of the eyebrows; to the third are to be reckoned the fine hairs on the face, on the trunk and extremities, also those on the *caruncula lacrymalis* and *labia minora*, which latter are often wanting.

The hairs are disposed either singly, or in twos or threes; sometimes, even, in fours and fives. The latter is generally their arrangement in the fœtus, but also occurs in the adult, especially in downy hairs. As *Osiander*, and particularly *Eschricht*, have proved, the direction of the hairs and hair-follicles is seldom straight, but usually oblique; and is different in the various parts of the body, which is easily shown in the hairs of the embryo, as also in adults, although less distinctly. The regularity depends upon this, that the hairs being arranged in curved lines, which either converge towards fixed points or lines, or diverge from them in two or several directions, a great number of figures arise, which may, with *Eschricht*, be designated *streams, whorls*, and *crosses.* Streams, with converging hairs, are met with in the mesial line of the back, the chest, and the abdomen, and in the line over the ridge of the shin-bone; streams with diverging hairs are found in the lateral line, separating the abdomen and thorax from the back, etc. Whorls and crosses with diverging hairs occur in the armpit, on the crown of the head, the internal angles of the eyes, and with converging hairs on the elbow. For more special details, I refer to *Eschricht's* drawings and descriptions.

§ 57. *Physical Properties and Chemical Composition of the Hairs.*—The hairs are very elastic; they admit of being extended nearly a third of their length, and when stretched only a fifth, they contract again so completely, that they remain extended only $\frac{1}{17}$th beyond their original length. They easily absorb water, and as easily give it off again; they are, accordingly, sometimes dry and brittle, sometimes moist and soft, according as the skin or the atmosphere contains much or little water. Their length alters with their degree of moisture, upon which property their employment as hygrometers is founded. Their strength, notwithstanding their extensibility, is considerable, and hairs of the head support at least six ounces without breaking.

The chemical composition of the hairs has not yet been sufficiently elucidated. Their chief constituent is a nitrogenous substance containing sulphur, which is soluble in alkalies with the development of ammonia, but insoluble in boiling concentrated acetic acid, and belongs to the albuminous class of compounds. The hairs contain, according to their tint, a greater or less amount of darker or lighter coloured fat, which can be extracted by boiling in ether or alcohol. According to *Mulder*, they are distinguished from horn and epidermis, especially by their insolubility in acetic acid, and by the same character, also, from albumen and fibrine. The hairs *resist decomposition* better than any other part of the body, so that even mummy hairs are found quite unaltered. By metallic oxides, the hairs are coloured exactly like the epidermis; thus they are rendered black by the salts of silver and manganese, while sulphurets of these metals are formed; chlorine, on the other hand, bleaches them. The ash amounts, on an average, from 1 to 2 per cent., and contains oxide of iron (more in dark hair), oxide of manganese and silica (traces); in white hairs, phosphate of magnesia and sulphate of alumina (*Jahn*).

§ 58. With reference to their finer structure, two substances may, without exception, be distinguished in all hairs, and in many even three: 1. the *cortical substance* (more properly, *fibrous substance*), which forms by far the most important part of the hair, and gives it its shape; 2. the *cuticle*, a delicate external covering on the fibrous substance; 3. the *pith*, or *medullary substance*, which is situated in the centre, and is often wanting.

The *cortical*, or *fibrous substance*, is longitudinally striped, very often darkly punctuated, and streaked or speckled; and always more or less intensely coloured, except in white hairs, in which it is transparent. The colour is sometimes distributed pretty uniformly through the whole substance, sometimes more concentrated in the form of elongated, granular spots. The more minute structure of the fibrous substance of the hair, as well as the nature of its spots and striæ, can only be sufficiently elucidated by the employment of acids and alkalies, usually much resorted to in the investigation of the hair, and by other modes of procedure. If a hair be treated with hot concentrated sulphuric acid, its fibrous substance may be separated, much more easily than before, into flat, long fibres of variable breadth (generally 0·002‴ to 0·005‴), which are distinguished especially by their stiffness and brittleness, and their irregular, even jagged, borders and extremities. In light hairs these fibres have a bright, in dark hairs a dark colour. These so-called hair-fibres are, however, not the ultimate elements of the cortical substance, but each of them must be regarded as an aggregation of long, flat, nucleated fibre-cells or plates, which, after thorough treatment with sulphuric acid, can be obtained isolated along with the fibres. These, which may be best designated *plates of the fibrous substance*, or *fibre-cells of the cortex*, are flat and, in general, spindle-shaped, 0·024‴ to 0·033‴ long, 0·002‴ to 0·004‴, even 0·005‴ broad, 0·0012‴ to 0·0016‴ thick, with uneven surfaces and irregular borders. They do not swell up into vesicles in caustic alkalies, and often present in their interior a darker streak of which we shall presently speak. Under certain circumstances, they also possess granular pigment; in other respects, they

Fig. 46.

Plates or fibre-cells of the cortical substance of a hair, treated with acetic acid; magnified 350 times. A. Isolated plates: 1. from the surface (three single, two united); 2. from the side. B. A bundle composed of many such fibre-cells.

are homogeneous, and no finer elements, such as fibrillæ, can be observed. They appear to be more intimately united with each other in the longitudinal direction than in the transverse, whence the easy splitting of the cortical substance into the above-mentioned long fibres. These fibres—which cannot well be designated as compound constituents of the cortical substance, inasmuch as their elements can be isolated, and they themselves are much too irregular—form a compact bundle, without evident lamellæ as in the nail and epidermis; and in this way produce the cortical substance, the principal constituent of the hair. The *dark spots, dots,* and *striæ* of the cortex are of different kinds, and are chiefly, 1. *granular pigment;* 2. *spaces filled with air or liquid;* and 3. *nuclei.* These spots, as is shown by caustic potass and soda, which soften and swell the cortical substance without acting upon the spots, are, for the most part, nothing but *aggregations of pigment granules,* which are situated in the plates of the hair, and vary very much in their size and form. A second kind of dark spots resemble very much depositions of pigment, but are found to be *small cavities filled with air.* These cavities are very numerous in white and fair hairs, but they are absent in quite dark hairs, and in the lower half of the roots of all hairs.

Lastly, there occur in the fibrous substance other moderately dark slender streaks, or lines, which are, 1. the *boundary lines* of the fibre-cells, and 2. their nuclei. All the plates of the fibrous substance in the shaft of the hair contain spindle-shaped nuclei, of 0·01‴ to 0·16‴ long, and 0·0005‴ to 0·0012‴ broad, which can be isolated by crushing white hairs which have been boiled in caustic soda. Moreover, fine streaks of another kind are observed in the fibrous substance, and especially in a *whitish part immediately above the bulb*, which are produced by inequalities on the surface of the plates forming the tissue.

The above description of the cortex, or fibrous substance, is especially applicable to the shaft of the hair. In the root, also, so far as it is hard and dry, essentially the same conditions are found; in its lower half, where it gradually becomes softer, finely fibrous, and then granular, the structure, too, becomes gradually altered. Here the above-described plates become softer, and assume more and more distinctly the form of elongated cells, of 0·020‴ to 0·024‴ long, and 0·009‴ to 0·011‴ broad, whose cylindrical, straight, or serpentine nuclei, of 0·008‴ to 0·01‴, become very perceptible on the addition of acetic acid, and can be easily isolated. While the fibrous character thus becomes more and more indistinct, the soft and shortened plates pass into oblong roundish cells, with short nuclei, which, finally, are continued without interruption into the elements of the lowermost thickest part of the hair, the bulb. These are round cells, of 0·003‴ to 0·006‴, which lie closely packed together, and, like the cells of the mucous layer of the epidermis, sometimes contain only colourless granules, sometimes are so filled with dark pigment-granules, that they are changed into true pigment-cells. We have still to mention, that the chemical properties of the elements of the fibrous substance are altered at the lower half of the root, inasmuch as they become more easily affected by acetic acid, which does not act upon the plates of the shaft at all, and also swell up and dissolve in alkalies much quicker than in the shaft.

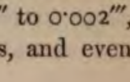
The colour of the fibrous or cortical substance depends, firstly, upon spots of pigment; secondly, upon air-cavities; and thirdly, upon a colouring matter combined with the substance of the plates constituting the tissue.

§ 59. The *medullary substance*, *substantia medullaris*, or *pith*, is a stripe or cord extending in the axis of the hair from above the bulb to near the apex. This substance is generally wanting in downy hairs, frequently also in the coloured hairs of the scalp; but is, for the most part, present in the short and thick, as well as in the stouter long hairs, and in white hairs of the head. By simply boiling white hairs in caustic soda until they swell out and coil up, the cellular structure of the medulla, now rendered transparent, may be often seen by mere compression of the softened hairs, and without further preparation. If such a hair be carefully teased out, it is very easy to isolate the *medullary cells*, either connected in rows, or even singly. They are rectangular or quadrangular, seldom roundish or spindle-shaped, cells, of 0·007‴ to 0.01‴ in diameter, here and there furnished with dark, fatty-looking granules; and, in many cases, when the alkali has not acted too strongly, with a roundish, distinct clear spot, of 0·0016‴ to 0·002‴, which evidently represents the rudiment of a nucleus, and even appears to swell up somewhat in soda. In the fresh hair, the medulla of the shaft is silver-white or dark, which appearance, as many more favourable objects show, is produced by irregularly roundish air vesicles, which fill the medullary-cells in large quantity — black (opaque), or white and shining, according to the illumination. Their nature can be readily perceived, when a white hair is boiled in water or ether, or treated with oil of turpentine, in both of which cases the medulla becomes quite clear and transparent. If such a hair, treated with water, be dried between the fingers, it regains quickly, often in a trice, and visibly to the naked eye, its former white colour; and if it is placed under the microscope immediately after drying, without fluid, or with fluid only at one end, nothing is easier than to see the air re-entering, and the medulla becoming dark again. Not only in white, but also in coloured hairs, the medulla contains air when examined in the *fresh condition.*

Fig. 47.

A portion of the root of a dark hair, slightly acted upon by caustic soda. *a*. Medulla, still containing air, and with cells, which appear pretty distinct; *b*. cortex with pigment spots; *c*. inner layer of the epidermis; *d*. outer layer of it; *e*. inner layer of the inner root-sheath (*Huxley's* layer); *f*. outer fenestrated layer (*Henle's* layer). Magnified 250 times.

Fig 48.



Eight medullary cells, with pale nuclei and fatty granules, from a hair treated with soda. Magn. 350 times.

The diameter of the medulla is, in general, to that of the hair itself as 1 to 3—5: it is relatively and absolutely thickest in short thick hairs, thinnest in woolly hairs and those of the head. In a cross section it has a round or flattened figure; and the cells which compose it are arranged in 1—5, or even more longitudinal rows.

According to *Reissner* and *Reichert*, the medulla contains in its interior a fine fibre, which is a prolongation of the hair-papilla; a statement which I have not hitherto been able to confirm.

§ 60. The *cuticle of the hair* is a very thin transparent membrane, which forms a complete covering for the hair, and is very firmly united with the cortical or fibrous substance. When viewed in its normal position and in an unaltered hair, its almost sole indications are numerous, dark, reticulated, irregular, and even jagged lines, which are distant 0·002‴ to 0·006‴ from each other, and extend round the hair, and small projections giving a serrate outline to its apparent border (fig. 49, A.). If a hair be treated with alkalies, the cuticle separates in larger or smaller shreds from the fibrous substance, and even breaks up into its elements. These are quite flat, non-nucleated plates, generally transparent and pale at the borders, and of a quadrangular or rectangular outline, which do not swell up into vesicles by means of re-agents. They are arranged like tiles on a roof, the lower cells overlapping the upper ones, and form a simple membrane, which entirely envelopes the cortex or fibrous part of the hair. In sulphuric acid, also, the structure of the cuticle can be easily perceived; the hair becomes ragged at the borders, from the projection of the plates, and then the cuticle can be easily scraped or rubbed off; but it is reduced to its constituent elements, and it is not easily obtained in larger patches.

Fig. 49.

A. Surface of the shaft of a white hair, magnified 160 times. The curved lines designate the free border of the epidermic plates. B. Epidermic plates from the surface, isolated by caustic soda, and magnified 350 times. Either one or both of their borders are folded, and consequently appear dark.

The cuticle consists of a single layer of plates or scales, which on the shaft is 0·002‴ to 0·003‴, on the root 0·0025‴ to 0·0035‴ thick; the plates measure, in the transverse direction, 0·024‴ to 0·28‴; in the longitudinal, 0·016‴ to 0·02‴; and are scarcely thicker than 0·0005‴. At the hair-bulb these plates pass rather abruptly into nucleated soft cells, which are broad in the transverse direction of the bulb, very short in the direction of its long axis, but somewhat longer in the direction which is perpendicular or oblique to the long axis of the hair. They are easily acted upon by alkalies and even by acetic acid, possess, without exception, transverse and tolerably long nuclei, and, finally, pass at the end of the bulb into the already-described round cells, of which the latter is formed.

§ 61. The *hair-follicles* are flask-shaped sacs, 1 to 3 lines long, which rather closely invest the roots of the hair, and in downy hair are situated in the substance of the upper layers of the corium, in strong or long hair, on the other hand, penetrate, for the most part, into its deeper parts, and even sink more or less deeply into the subcutaneous cellular tissue. They are to be looked upon simply as continuations of the skin with its two constituent parts, the corium and epidermis; and, accordingly, we distinguish in each of them an external, fibrous, vascular portion, the proper hair-sac, and a non-vascular lining, consisting of cells and surrounding the hair — the *root-sheath*,— which is partly to be regarded as the epidermis of the hair-follicle, partly as a special sheath for the root of the hair.

§ 62. The proper hair-sac, or follicle, consists of two fibrous coats, an external and an internal, and of a structureless membrane; it is, on an average, 0·015‴ to 0·022‴ in thickness, and possesses at its base a peculiar structure, the *papilla of the hair*.

The *external fibrous coat*, the thickest of the three layers of the hair-follicle, determines its external form, and is very intimately connected by its uppermost part with the corium. It consists of ordinary connective tissue with longitudinal fibres, without elastic fibres, but with a good many elongated, spindle-shaped, small cells; it is supplied with a tolerably rich net of capillaries and a few nerve-fibres, with sparing divisions.

The *internal fibrous coat* is much more delicate than the external; it is bounded by smooth surfaces, is everywhere equally thick, and extends from the base of the hair-follicle only as far as the point of junction of the sebaceous glands. It is, to all appearance, destitute of vessels and nerves, and consists of a simple layer of transverse fibres with long slender nuclei, which are particularly easy of observation in the empty hair-follicles of both coarse and fine hairs, with or without the employment of acetic acid. They resemble smooth muscular fibres, but cannot be completely isolated, so as to be positively recognised as spindle-shaped fibres with a single nucleus, so that I cannot, for the present, express myself decidedly as to their nature; and the more so, as we have no facts to show that contractions of the hair-follicles take place.

The third layer is a *hyaline structureless membrane*, which, when the hair is pulled out, always remains behind in the hair-follicle, and, in connection with and also covering the papilla [illegible], extends from its base as far as the internal root-sheath, and perhaps higher. It appears, in the uninjured hair-follicle, only as a very pale streak, 0·001''' to 0·0015''', seldom 0·002''', in thickness, between the external root-sheath and the transverse fibrous layer of the hair-follicle; but, by preparation of an empty hair-follicle, it may be easily obtained in considerable patches. It then appears smooth externally, but internally presents very delicate, transverse, often anastomosing lines, which, like the membrane itself, are not altered by diluted acids or alkalies. Neither alkalies nor acids cause cells or nuclei to appear in this membrane, and it belongs, accordingly, to the class of the true structureless membranes.

The *papilla of the hair*, less fitly termed hair-germ (*pulpa pili*), belongs to the follicle, and represents a papilla of the cutis. It is a beautiful ovate or fungiform papilla, $\frac{1}{8}'''$ to $\frac{1}{16}'''$ broad, $\frac{1}{11}'''$ to $\frac{1}{[illegible]}'''$ long, and is connected by a pedicle with the connective-tissue-coat of the follicle; it has a sharp outline, and a perfectly smooth surface; in its structure, it harmonises completely with the papillæ of the cutis, and consists of an indistinctly fibrous connective tissue, with scattered nuclei and fat-granules, but without cells. It contains, also, in man and in animals, vessels; but no one has as yet been able to demonstrate nerves in it.

§ 63. The *root-sheath* may be divided into an external and an internal layer, of which the former is continuous with the epidermis round the opening of the hair-follicle, and appears as the epidermic lining of the follicle; while the internal is an entirely independent layer, and enters into direct relation with the hair.

The *external root-sheath* is a continuation of the mucous layer of the epidermis, invests the entire hair-follicle, and rests in its lower half on the above-described structureless membrane; higher up, where the latter and the transverse fibres are no longer present, it lies immediately upon the longitudinal fibrous layer. In structure, it corresponds entirely with the mucous layer; like the latter, also, the outermost cells are perpendicularly placed. These last-mentioned cells are, in the negro, brown throughout, and in the white races, at least in the hairs of the *labia majora*, are brown in the upper part. At the bottom of the hair-follicle the external sheath, while its cells become gradually round, passes continuously, and without any boundary line, into the round cells of the hair-bulb which cover the papilla. The external root-sheath is generally about 3 to 5 times as thick as the internal; but not unfrequently it becomes somewhat attenuated superiorly, and below is invariably prolonged into a very thin lamella. In coarse hairs, it measures in the middle of the root 0·018‴ to 0·03‴, and possesses 5 to 12 layers of cells.

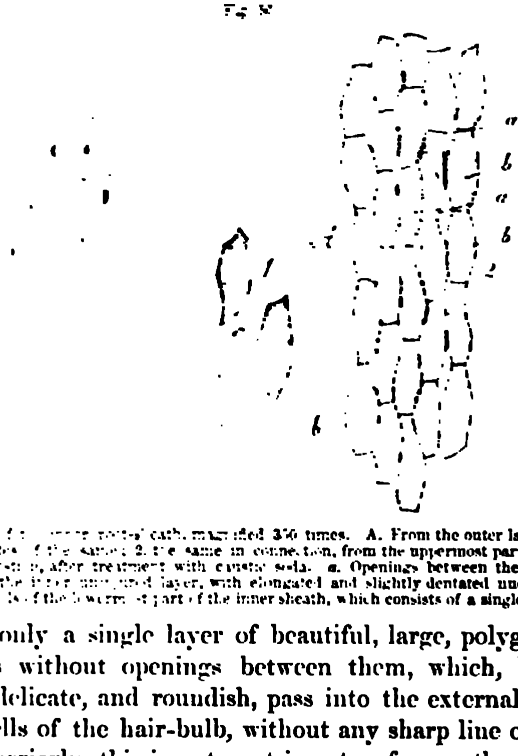
The *internal root-sheath* is a transparent membrane, which extends almost from the bottom of the hair-follicle over nearly two-thirds of it, and then ends abruptly. It is connected externally with the outer sheath, internally with the cuticle of the hair, so that, in the normal condition, no space is found between it and the hair. It is especially characterised by its great firmness and elasticity, and consists, except in its lowest part, of two layers, the *proper internal sheath* and the *cuticle*, which, in order to distinguish it from that of the hair, must be designated the cuticle of the internal root-sheath.

The *proper internal sheath* presents two, or even three layers of polygonal, elongated, transparent and somewhat yellowish cells, all of which lie with their longitudinal axes parallel to that of the hair. The most external layer (fig. 50, A.), is formed of elongated, non-nucleated cells, 0·016‴ to 0·02‴ in length, and 0·004‴ to 0·006‴ in breadth, which are intimately united in the longitudinal direction; and in the usual method of examination, after the addition of acetic acid, soda, or potass, which make the hair swell up, or after it has been teased out, exhibit elongated narrower and wider fissures, thus presenting the appearance of a fenestrated membrane. In perfectly fresh hairs, however, if all re-agents and mechanical violence be avoided, for the most part not a trace of openings is seen in the upper half of the layer in question; and in the lower (from the finely fibrous part of the cortex downwards), at the most only indications of them, in the form of bright or dark streaks (according to the focus), similar to those of the fibrous substance of the shaft. We are forced, therefore, to regard these openings as they are commonly seen (0·005‴ to 0·008‴ in length, and 0·001‴ to 0·003‴ in breadth), as produced artificially by the tearing of the membrane. Secondly, cells also occur in the root-

[illegible] fissures between them. These (fig. [illegible] single or double layer (*Huxley's* layer), [illegible] than the cells above described (0·014‴ to [illegible] broad); likewise, however, poly- [illegible] at least in the lower half of the root-sheath, [illegible] pointed nuclei, 0·004‴ to 0·006‴. The [illegible] inner root-sheath amounts, on an average, [illegible] whence it is evident that its cells, which at [illegible] are at least 0·002‴ to 0·0025‴ in thickness. [illegible] preparation in their natural position, [illegible] root-sheath; they are easily isolated in soda [illegible] swelling up — a character which, as [illegible] resistance to the actions of alkalies in [illegible] cuticular plates of the hair.

At the bottom of the hair-follicle, the proper inner root-sheath

Fig. [illegible]



[illegible] root-sheath, magnified 350 times. A. From the outer layer. 1. [illegible] the same in connexion, from the uppermost parts of the [illegible], after treatment with caustic soda. *a.* Openings between the cells *b.* B. [illegible] layer, with elongated and slightly dentated nuclei. C. [illegible] part of the inner sheath, which consists of a single layer.

consists of only a single layer of beautiful, large, polygonal, nucleated cells without openings between them, which, becoming at last soft, delicate, and roundish, pass into the external layers of the round cells of the hair-bulb, without any sharp line of demarcation. Superiorly, this investment is not unfrequently somewhat separated from the hair. It terminates near the openings of the sebaceous glands in a sharp, dentated border, which is formed by its cells individually more or less projecting. Thence upwards, its place is occupied by the external root-sheath, the innermost cells of which soon assume all the characters of those of the horny layer of the epidermis.

The *cuticle of the inner root-sheath* is closely applied to the interior of the root-sheath in its whole extent, and resembles very much the cuticle of the hair itself, which it immediately adjoins. It becomes especially distinct on the addition of caustic potash or soda, frequently detaches itself on pressure from the hairs, along with the inner root-sheath; while the cuticle of the hair, thrown into undulating creases, remains lying upon the fibrous substance, and in this condition can be studied with facility, both in a profile and superficial view. In torn-out hairs, this layer is only found when they are still covered by the inner root-sheath, otherwise it remains behind in the hair-follicle. It consists of non-nucleated, imbricated, broad cells, which never swell up, and which dissolve with difficulty in alkalies; they are, however, thicker than those of the cuticle of the hair, and measure in the longitudinal direction of the hair only 0·002‴ to 0·004‴. The whole of this layer measures 0·0016‴ to 0·002‴, and is continued, at the hair-bulb, with a tolerably distinct line of demarcation, into large nucleated cells, disposed in the same manner as those into which the cuticle of the hair itself passes, except that they are generally smaller.

I regard, with *Reichert*, the outer root-sheath as the epidermis of the follicle, and the inner, together with its cuticle, as an independent layer belonging to the hair; only I cannot admit, as *Reichert* seems to do, that the inner root-sheath, with its cuticle, continues to grow in the developed hair.

§ 64. *Development of the Hairs.*—The first rudiments of the hairs are flask-shaped, solid processes, entirely composed of cells, formed *by the growth inwards of the mucous layer of the epidermis*, in which the inner and outer cells become modified in such a way that the former are converted, first, into a small delicate hair in the axis of the rudiment, and, secondly, into an internal sheath surrounding this (both being transformed into a horny substance); while the latter remain more unaltered and soft, and appear as the external sheath and soft cells of the hair-bulb. The hairs and sheaths, therefore, are developed at once in their totality; the former as miniature hairs, with root, shaft, and point. Thus the point is not first formed, as is the case with the crown of the teeth, and still less can it be said that the hair begins with the root, as has been *sometimes supposed*. The elements of the youngest hairs are nothing but elongated cells, similar to those of the fibrous substance of the subsequent hairs, which arise by the lengthening and chemical metamorphosis of the innermost cells of the hair-rudiments. Medullary cells are wholly absent; on the other hand, the cuticle is very obvious. The inner sheath is striated, exhibits no gaps, and consists of elongated cells, which have been developed from the cells situated between the hair and the outer sheath. The proper hair-follicle, as regards its fibrous layers, is formed *in loco* from the formative cells of the cutis, which surround the hair-rudiment. It may, however, be conceived as an inversion of the cutis, connected with the inward growth of the processes of the epidermis. Its structureless membrane, which appears so early, may be closely related to the external cells of the hair-rudiment, which correspond to the outer root-sheath, and, like the membranæ propriæ, may be formed by an excretion from them. As to the hair-papilla, we cannot but regard it as a growth of the fibrous part of the hair-follicle, analogous to the papillæ of the corium in general.

The first rudiments of the downy hairs, and of their sheaths, are found in the human embryo at the end of the third or the commencement of the fourth month, on the forehead and eyebrows; they consist of papilliform collections of cells, 0·02‴ in diameter (fig. 51). In the fifteenth week the processes are larger (0·025‴ to 0·05‴ long, 0·013‴ to 0·02‴ broad), flask-shaped, and surrounded by a delicate covering, which is continuous with a delicate membrane between the *rete Malpighii* and *cutis*, but more intimately united with the former.

Fig. 51.

Hair-rudiments, from the forehead of a human embryo, sixteen weeks old; magnified 350 times. *a.* Horny layer of the epidermis; *b.* mucous layer of the same; *i.* structureless membrane surrounding the hair-rudiment, and continued between the mucous layer and the corium; *m.* rounded, in part elongated cells, of which the hair-rudiment is principally composed.

Besides this covering, which is, indeed, nothing but the structureless membrane discovered by me in the fully-developed hair-follicles, another and more exterior layer of cells occurs on the hair-follicles, which generally comes away with them from the cutis in shreds, rarely entire. I look upon this as the first indication of the fibrous layers of the hair-follicles. In the sixteenth and seventeenth weeks, the processes of the mucous layer, which I shall henceforth simply call *hair-rudiments*, enlarge up to 0·04‴ to 0·06‴ in length, and 0·03‴ to 0·04‴ in breadth, and their coverings become thicker, although they do not present as yet the least trace of a hair. In the eighteenth week, the first indications of the hairs are seen in the eyebrows, in hair-rudiments of 0·1‴ and 0·2‴, their central cells being lengthened, and their long axis disposed parallel to that of the rudiment; whilst the peripheral cells are arranged with their long diameter transversely.

Thus a diversity of shade arises in the hitherto homogeneous hair-rudiment, and a central, conical mass, broad below and running out into a point above, becomes distinguished from an external portion, which is narrow below and thick above. When the hair-rudiment is 0·22‴ long, this demarcation becomes still more evident, as the somewhat longer, and especially broader, inner cone acquires a clearer aspect. Lastly, in hair-rudiments of 0·22‴ long, the inner cone becomes distinguished into two parts: a central, somewhat darker, and an external, wholly transparent, and hyaline portion, *the hair and the inner root-sheath*; whilst the peripheral cells, which have remained opaque, form undoubtedly the outer root-sheath (fig. 52). At the same time, the hair-papilla, of which there were before slight traces visible, becomes more distinct, and the proper hair-follicle more perceptible, as the cells which are situated external to its structureless membrane begin to pass into fibres, which may already be recognised by their decussation. The hair-follicles and hairs are developed, in other places, exactly in the same way as in the eyebrows, except that their formation takes place at a later period. In the fifteenth week, there are no hair-rudiments to be seen, except on the forehead and eyebrows in the sixteenth and seventeenth weeks, they appear over the whole head, back, chest, and abdomen; in the twentieth week, on the extremities. The hairs themselves are never visible earlier than three to five weeks after the formation of the rudiments. Thus, for example, in the nineteenth week, no hairs are to be seen anywhere in the rudiments, except on the forehead and eyebrows; in the twenty-fourth week, they are still wanting upon the hand and foot, and, in part, upon the fore-arm and leg.

Fig. 52.

A. Hair-rudiment, with just developed but not erupted hair, of 0·28‴ in length. The inner root-sheath somewhat surmounts the point of the hair, and laterally, at the neck of the follicle, two papilli-form outgrowths of the outer root-sheath present the first rudiments of the sebaceous glands. B. Hair-follicle from the eyebrows, with a hair which has just erupted. The inner root-sheath projects into the aperture of the hair-follicle; no rudiments of sebaceous glands are as yet present. *e.* hair-bulb; *f.* hair-shaft; *g.* point of the hair; *n.* rudiments of the sebaceous glands.

When once formed, the hairs and hair-follicles increase in size; the former sometimes penetrate the epidermis immediately (eyebrows, eyelashes), sometimes, in company with the inner root-sheath which likewise becomes lengthened, they push their points between the horny and mucous layers, or even into the substance of the horny layer itself, and continue to grow for some time longer under the epidermis (chest, abdomen, back, extremities [?]) which they at last penetrate. Involutions of the skin, which grow towards the penetrating hairs, are never seen, and the notion that such involutions exist, has no real foundation.

The downy hairs (*lanugo*), the eruption of which is completed by the twenty-third to the twenty-fifth week, are short fine hairs, whose peculiar disposition has been mentioned above. They measure at the bulb, 0·01‴; in the shaft, 0·006‴; at the point, 0·0012‴ to 0·002‴. They are light-blond, or almost colourless, and consist only of fibrous substance and cuticle. The bulb, in man, is generally colourless, and rests upon a very distinct papilla, which arises, as usual, from the bottom of the hair-follicle. This has the same three layers as in the adult, and a very well developed epidermic lining, viz., an external root-sheath of 0·004‴ to 0·012‴, and an internal root-sheath of 0·006‴ to 0·008‴, without apertures.

After their eruption, the downy hairs continue to grow slowly to a length of $\frac{1}{4}$ to $\frac{1}{3}$ of a line, and to a greater length on the head than in other parts. The majority remain to the end of fœtal life, and become gradually darker; in many cases, as on the head, even blackish; whilst a very small portion fall off into the liquor amnii, along with which they are often swallowed by the fœtus, and are then found in the *meconium*. A proper shedding of the hairs does not, as far as I can see, take place at all during embryonic life, and the infant is born with the *lanugo*; nor is there any trace to be seen of a further formation of hair-rudiments after the complete eruption of the *lanugo*.

§ 65. *Shedding of the Hair.*—After birth, *a total shedding of the hair takes place, by new hairs arising in the follicles of the downy hairs, and gradually displacing the old ones.* This shedding of the hairs, which I discovered in the eyelashes of a child one year old, is caused by an increased growth of the soft round cells of the hair-bulb, and of the adjoining outer root-sheath at the bottom of the follicle of the old hair, whereby there is produced an elongated process or mass of cells, which is interposed between the hair and its papilla, so that the hair becomes detached from the latter, and is, at the same time, also hardened or cornified in its lowest part. When the above-mentioned process has attained a length of 0·25‴ (fig. 53, A.), a differentiation of its external and internal cells takes place, similar to that which was described above while speaking of the origin of the downy hairs in their cellular rudiments. Whilst, namely, the outer cells remain round and colourless,

Fig. 53.

Hairs of the eyelashes of a child, one year old; magnified 20 times. A. With a process of the bulb or external root-sheath, of 0·25‴ in length, in which the central cells are elongated (their pigment is not here represented), and distinctly marked off from the outer ones in the form of a cone. B. With a process, of 0·3‴ in length, in which the inner cone is transformed into a hair and an inner root-sheath. The old hair has moved further upwards, and like as in A, is devoid of an inner root-sheath. *a*. Outer; *b*. inner root-sheath of the young hair; *c*. hair-cells of the papillæ; *d*. bulb; *e*. shaft of the old hair; *f*. bulb; *g*. shaft; *h*. point of the young hair; *i*. sebaceous glands; *k*. three sudoriparous ducts, which in A. open into the upper part of the hair-follicle; *l*. transition of the outer root-sheath into the mucous layer of the epidermis.

as they were previously, the inner ones begin to develop pigment in their interior and to lengthen; being marked off at the same time from the former as a conical-shaped mass, with its apex directed upwards. At first, this central mass is perfectly soft, and, like the layers of cells which surround it externally, easily soluble in soda. At a later period, however, after it, as well as the including process, has grown somewhat in length, its elements become harder, and separate into two portions, an inner dark pigmented, and an outer bright portion, which are, in fact, a young hair with its inner sheath (fig. 53, B.). The young hair, the point of which at first does not project beyond its inner root-sheath, gradually reaches with its point to the opening of the old hair-follicle, whilst, at the same time, its root-sheath becomes elongated. At length it passes out, and appears at the same opening with the old hair, which, in the meantime, has been more and more pushed upwards. When the development of the young hair is thus far advanced, the last stage can be easily comprehended. The old hair, which has long ceased to grow, and has lost its connection with the bottom of the follicle, falls out; whilst the young hair becomes larger and stronger, and fills up the vacuity left by the old one. I regard the development of the above-described process of the hair-bulb and outer root-sheath at the bottom of the follicle as the *primum movens* of the death and shedding of the old hair. As the follicles are not correspondingly elongated, the process in question pushes upwards all the parts lying above it, and continually increases the distance separating the hair-papilla from the proper substance of the old hair, *i. e.*, the part at which the round cells of the bulb commence to elongate and to be converted into a horny substance. Thus the hair is raised, as it were, from its nutrient soil, receives a less and less supply of blastema, finally, ceases to grow, and in its lowermost part, as well as above, is converted into horny matter. The cells of the process, on the other hand, which are in connection with the papilla, continually draw new formative material from it, which, for the time being, they use, not for the formation of horny matter, but for their own growth. Thus the intervening process attains a greater and greater length, and pushes, in a purely mechanical manner, the old horny hair-root, together with its sheath, quite to the aperture of the sebaceous glands, where, to all appearance, a partial solution of the old sheath takes place, which can be demonstrated with certainty in the inner sheath, and must be presumed to take place in the outer also.

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[illegible] which precedes the shedding of
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[illegible] and whether repetitions of the
[illegible] later period.

[illegible] the new hairs are likewise [illegible] of *Heusinger* and [illegible] and *Schultz* show; [illegible] *Langer* does not [illegible] appear to be exactly the same [illegible]

[illegible] —[illegible] possess a determinate [illegible] the sex of the individual, [illegible] with the other horny [illegible] growth of hair proceeds is, [illegible] Here new elements [illegible] —through means of a blastema [illegible] of the hair-follicle itself—by the [illegible] cells there situated, while the [illegible] somewhat higher placed, are [illegible] the middle ones into the cells of the [illegible] the plates of the fibrous [illegible] epidermic scales: and thus the [illegible] continually pushed from below upwards, and elongated. In the latter no formation of elementary parts occurs, at most only a certain alteration of those already existing, which causes a gradual thinning of the root from the bulb upwards, until it is reduced to the thickness of the shaft. Higher up even these changes of the elementary parts are wanting; consequently hairs, when cut, do not acquire new points. The root-sheaths and the outer layer of the hair-cuticle do not take part in the growth of cut hairs.

The fully-developed hair, although destitute of vessels, is not a dead structure. Although the vital changes going on in it are still altogether shrouded in obscurity, still we may assume, that it is permeated by fluids, and employs them for its nourishment and maintenance. These fluids come from the vessels of the papilla and follicle, ascend probably in chief part from the bulb, through the cortical substance, and penetrate into all parts of the hair, although there are no special canals for this purpose to be found in the tissue. When these fluids have served for the nutrition of the hair, they are exhaled from its outer surface and replaced by new portions. Perhaps, also, the hairs absorb fluids at the surface, either as liquid or vapour, exactly like a hygrometric hair; on the other hand, I cannot believe that the secretion of the sebaceous glands penetrates the hairs from without, as many authors appear to assume, since the perfectly-continuous hair-cuticle is, in fact, impervious to it. In like manner, it appears to me still by no means proved, that the hairs are permeated by a special oily fluid (*Laer*), coming from the medullary substance (*Reichert*), and keeping them in an unctuous condition; for such a fluid cannot be demonstrated, and the unctuous character of the hairs is easier explained by the sebaceous secretion of the skin, which, as may be easily seen, adheres to them externally. The formation of air in the medulla can depend only upon a disproportion between the supply of fluid from the hair follicle and that which goes off by evaporation; it is, as it were, a desiccation of the hairs, although it must not be thought that the hair is entirely deprived of moisture in its aeriferous portions. But, doubtless, the aeriferous portions are to be regarded as the most inactive, and as relatively dead parts of the hair, whilst the fibrous substance, which is also easiest altered by the action of alkalies, notwithstanding the apparent hardness and rigidity of its elements, must be considered as richest in fluids, and as taking the largest share in the nutrition of the hair. The hair must, therefore, be regarded as endowed with life, and dependent in a certain way upon the entire organism; but upon the skin, in particular, from whose vessels (those of the hair-follicle) it draws the materials necessary to its existence. From the condition of the hairs, therefore, as *Henle* aptly observes, we may draw a conclusion of the degree of activity of the skin itself. If they be soft and shining, the skin is turgescent and actively exhalent; if they be dry, brittle, and rough, we may infer a certain degree of collapse of the surface of the body. The falling out of the hairs certainly depends, in many cases—as, for example, when it occurs in the course of normal development– merely on the want of the necessary nutrient material, which, i the natural moulting of the hairs, as already explained, is owin to the separation of the hair from its nutrient matrix, caused b the exuberant growth of cells at the bottom of the follicle; bu in old age, it may simply depend upon the obliteration of th vessels of the hair-follicle. The whitening of the hair also, whic depends chiefly upon a decoloration of the fibrous substance, an less upon that of the almost colourless pith, is, doubtless, partly t be referred to the same cause, for its normal appearance, i advanced age, shows it to be also of the nature of a retrogressiv change. The frequent cases in which the hair first becomes gra at the point or at the middle, and the well-authenticated instance of its rapidly becoming white are interesting, and speak strongl for the vitality of the hair; although it is not yet known wha peculiar processes in the elements of the hair occasion the decolor- ation of its different pigments.

As in the earliest periods of life the cast-off hairs are replace by new ones, so we find something similar occurring at a late period. It is quite certain that during the vigorous period of lif there is a continual replacement of the numerous hairs which ar shed; further, that at the time of puberty new hairs shoot fort in great numbers in certain localities, but how is unknown. Sinc in the adult there are hair-roots with small processes downwards whose proper hair has an abrupt knob-shaped end, as in the child; since further, two hairs not unfrequently come out at one opening and can even be demonstrated existing together in one follicle; and, lastly, since the roots of hairs which have fallen out sponta- neously, are exactly similar to those of the cast-off hairs of the first casting, it may be assumed that a real shedding also occurs at a later period, and in such a manner that the old follicles produce new hairs, and cast off the old ones, as has, in fact, been proved by *Langer*. By this, however, I do not mean to assert that a forma- tion of hairs from new rudiments does not also occur after birth; only this much, that in the adult, as in earlier periods, they are *regenerated* from the pre-existing hair-follicle. This will appear the more probable when it is recollected that, according to the observa- tions of *Heusinger*, the tactile hairs of dogs, when pulled out, are, within a few days, reproduced in the same follicle; and, also, that in the shedding of the hair in adult animals, the young hairs are, according to *Kohlrausch*, developed from the old follicles. Also, when the hairs which have fallen out after a severe illness, are reproduced, it is more probable that they are developed in the old follicles than that they are entirely new formations; since, according to *E. H. Weber*, the follicles of cast-off hairs continue to exist for a long time.

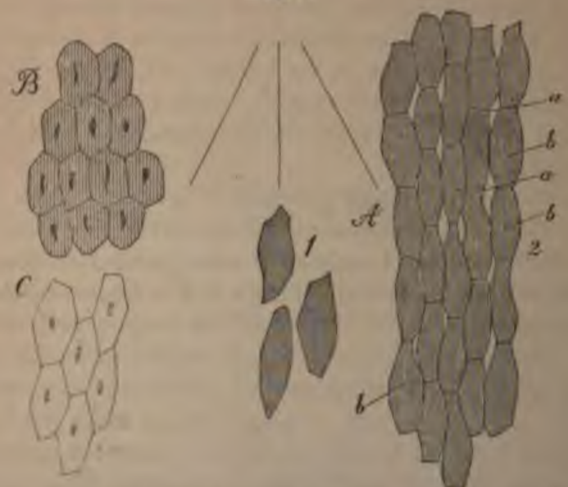
The reason why the hairs continue to grow, as long as they are cut, otherwise not, is the same as I already adduced in the analogous case of nails. The vessels of the papillæ yield a certain quantity of nutritive fluid, just so much as suffices to keep the whole hair continually moist, and to maintain it in a state of vitality. If the hair be cut, there is more nutritive fluid present than the hair requires, and thus it grows from the surplus of the supply, until it has again attained its typical length, and so it continually grows, if it be continually clipped.

Dzondi, *Tieffenbach*, and *Wiesemann*, have succeeded in transplanting the hairs with their follicles. Hairs arise, also, in abnormal localities, *e.g.* on mucous membranes, ovarian cysts, encysted tumours, and possess in all these cases, even in the lungs (*Mohr's* case), follicles, root-sheaths, and an otherwise normal structure. Cicatrices of the skin remain destitute of hairs. We cannot say upon what depends the occasional occurrence of excessive growth of the hair, or of an abnormal general shedding, together with repeated reproduction. Probably increased or diminished exudation from the vessels of papillæ and hair-follicles are the chief, the condition of the skin, and of the entire organism, the remote causes of these phenomena. Baldness, limited to a particular spot (*alopecia circumscripta*), may be caused by vegetable growth (fungi) in the interior of the hair itself, or under the cuticle of the hair, and around it. The turning gray of the hair is also unexplained, although the nervous system may evidently be concerned in causing it (grief, arduous mental exertions). It is not until physiology and chemistry have made us better acquainted with these last-mentioned processes, that we can think of a scientific pathology and therapeia of the hair.

For *microscopical examination*, a white hair with its follicle should be selected, afterwards also coloured ones. Transverse sections may be procured either by shaving twice at short intervals (*Henle*), or cutting hair upon a glass (*H. Meyer*), or a bundle of hairs between two cards (*Bowman*), or grasped in a cork (*Harting*); *Reichert* uses for this purpose hairs fixed in gutta percha. Longitudinal sections may be obtained by scraping a fine or splitting a coarse hair. The hair-follicle may be examined, isolated, and with the hair; its different layers may be separated by a nice dissection, and the nuclei of the two external ones may be perceived on the addition of acetic acid. As to the papilla we have already given the necessary information. The outer root-sheath, with its upper part, often wholly accompanies the hair when torn out; in the macerated skin it is very easily detached with the hair; the cells may be seen without addition, or by means of a little acetic acid or caustic soda. The inner root-sheath is often found entire in torn-out hairs, and may, without further preparation, or after removal of the outer sheath, be seen in all its parts. Potash and soda make it still more distinct after they have acted for a short time. The hair-cuticle must be examined particularly with alkalies and sulphuric acid, as also the hair itself; what is most important in reference to this has been already mentioned, and for further details consult *Donders* (l. c.). I will only mention that here also the sheath, which never present fissures between them. These (fig. 50, B.), which constitute a simple or double layer (*Huxley's* layer), are shorter and broader than the cells above described (0·014‴ to 0·018‴ long, 0·006‴ to 0·009‴ broad); likewise, however, polygonal, and possess, at least in the lower half of the root-sheath, distinct, elongated, often pointed nuclei, 0·004‴ to 0·006‴. The thickness of the entire inner root-sheath amounts, on an average, to 0·006‴ to 0·015‴; whence it is evident that its cells, which at most form three layers, are at least 0·002‴ to 0·005‴ in thickness. They can be seen without preparation in their natural position, and by teasing out the root-sheath; they are easily isolated in soda and potash, without, however, swelling up — a character which, as well as their considerable resistance to the actions of alkalies in general, they share with the cuticular plates of the hair.

At the bottom of the hair-follicle, the proper inner root-sheath

Fig. 50.



Elements of the inner root-sheath, magnified 350 times. A. From the outer layer. 1. Isolated plates of the same; 2. the same in connection, from the uppermost parts of the layer in question, after treatment with caustic soda. *a*. Openings between the cells *b*. B. Cells of the inner uninjured layer, with elongated and slightly dentated nuclei. C. Nucleated cells of the lowermost part of the inner sheath, which consists of a single layer.

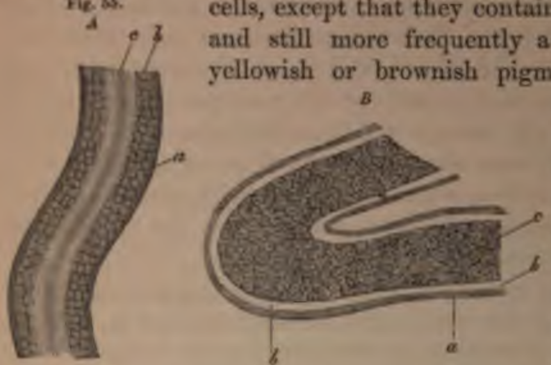
consists of only a single layer of beautiful, large, polygonal, nucleated cells without openings between them, which, becoming at last soft, delicate, and roundish, pass into the external layers of the round cells of the hair-bulb, without any sharp line of demarcation. Superiorly, this investment is not unfrequently somewhat separated from the hair. It terminates near the openings of the sebaceous glands in a sharp, dentated border, which is formed by its cells individually more or less projecting. Thence upwards, its place is occupied by the external root-sheath, the innermost cells of which soon assume all the characters of those of the horny layer of the epidermis.

The *cuticle of the inner root-sheath* is closely applied to the interior of the root-sheath in its whole extent, and resembles very much the cuticle of the hair itself, which it immediately adjoins. It becomes especially distinct on the addition of caustic potash or soda, frequently detaches itself on pressure from the hairs, along with the inner root-sheath; while the cuticle of the hair, thrown into undulating creases, remains lying upon the fibrous substance, and in this condition can be studied with facility, both in a profile and superficial view. In torn-out hairs, this layer is only found when they are still covered by the inner root-sheath, otherwise it remains behind in the hair-follicle. It consists of non-nucleated, imbricated, broad cells, which never swell up, and which dissolve with difficulty in alkalies; they are, however, thicker than those of the cuticle of the hair, and measure in the longitudinal direction of the hair only 0·002‴ to 0·004‴. The whole of this layer measures 0·0016‴ to 0·002‴, and is continued, at the hair-bulb, with a tolerably distinct line of demarcation, into large nucleated cells, disposed in the same manner as those into which the cuticle of the hair itself passes, except that they are generally smaller.

I regard, with *Reichert*, the outer root-sheath as the epidermis of the follicle, and the inner, together with its cuticle, as an independent layer belonging to the hair; only I cannot admit, as *Reichert* seems to do, that the inner root-sheath, with its cuticle, continues to grow in the developed hair.

§ 64. *Development of the Hairs.*—The first rudiments of the hairs are flask-shaped, solid processes, entirely composed of cells, formed *by the growth inwards of the mucous layer of the epidermis*, in which the inner and outer cells become modified in such a way that the former are converted, first, into a small delicate hair in the axis of the rudiment, and, secondly, into an internal sheath surrounding this (both being transformed into a horny substance); while the latter remain more unaltered and soft, and appear as the external sheath and soft cells of the hair-bulb. The hairs and sheaths, therefore, are developed at once in their totality; the former as miniature hairs, with root, shaft, and point. Thus the point is not first formed, as is the case with the crown of the teeth, and still less can it be said that the hair begins with the root, as has been sometimes supposed. The elements of the youngest latter possess an external covering of indistinctly fibrous connective tissue with elongated, scattered nuclei, which is sharply bounded internally by a delicate *membrana propria*, and this is lined within with a simple, double or multiple layer of polygonal cells of 0·005‴ to 0·007‴. These cells entirely resemble, in their chemical and other characters, the deeper pavement-epithelial cells, except that they contain some fat-granules, and still more frequently a small number of yellowish or brownish pigment-granules. The *thick walled* sudoriparous glandular canals have, in addition to the two coats above described, a middle layer of longitudinal, smooth muscular fibres, whose elements are readily separable. In all cases in which the glandular canals contain only fluid, the epithelium is a simple, very distinct layer of polygonal cells of 0·006‴ to 0·015‴; in the opposite case it can be seen only with difficulty, or not at all. With regard to the occurrence of these two forms of glandular canals, it is found that thick walls and a muscular structure occur especially in the larger glands of the axilla, whose tubes all possess muscular walls, and thence acquire a peculiar striated appearance. A structure in all respects similar I have found only in the large glands at the root of the penis and on the nipple; although a partially developed or less strongly marked muscular structure undoubtedly exists in some other places, particularly in the glands of the palm of the hand, whose wide canals are remarkable for the thickness of their walls, and present muscular fibres distinctly to be seen, although not so well marked as elsewhere. This remark applies also to particular glands on the scrotum and even on the back, the *labia majora*, the *mons Veneris*, and in the neighbourhood of the anus—but with this qualification, that often but a small part of the glandular tube, or even only its ultimate blind extremity is provided with muscular fibres. The glands of the leg, penis, breast (the areola excepted), the eyelid, and the majority of those of the back, the thigh and

Fig. 55.



Sweat ducts, magnified 350 times. A. One with thin walls and a central cavity without a muscular coat from the hand; *a*. connective investment; *b*. epithelium; *c*. cavity. B. A portion of a canal without a cavity, and with a delicate muscular layer from the scrotum; *a*. connective tissue; *b*. muscular layer; *c*. cells in the canal with yellow granules in their contents.

abdomen, as well as the first two segments of the upper extremities, have delicate walls, and are destitute of muscles.

The diameter of the glandular canals varies, in the smaller glands, from 0·022‴ to 0·04‴, and amounts, on an average, to 0·03‴; the thickness of the walls 0·002‴ to 0·003‴, the epithelium 0·006‴, and the cavity 0·004‴ to 0·01.‴ Some of the glands of the axilla possess canals of 0·07‴ to 0·1,‴ and even 0·15‴ in diameter, with walls (without reckoning the epithelium) of 0·006‴ thick, of which the half belongs to the muscular layer; but others, and in fact, the largest, have canals of only 0·03‴ to 0·06‴ in diameter, with walls of 0·004‴ in thickness. In the areola and on the genitals the diameter also varies in the larger glands, but within narrower limits.

Between all the coils of the sudoriparous glands connective tissue penetrates (occasionally with fat-cells), which conducts their vessels, and connects the windings of their tubes; in some cases there is an outer fibrous envelope (ordinary connective tissue with fusiform nuclei), surrounding the whole coil, which is particularly well-developed in those lying free in the subcutaneous connective tissue (penis, axilla, etc.).

§ 69. *Secretion of the Sudoriparous Glands.*—All the smaller glands contain, as soon as a cavity becomes apparent within them (which, however, is not always the case), only a clear, transparent fluid, without any structural constituents; the contents of the glands of the axilla, on the other hand, are rich in such constituents. The secretion in the latter case appears, in the first place, as a gray, transparent, slightly fluid substance, with innumerable fine, pale granules, and often with scattered nuclei; and, secondly, as a whitish-yellow, tolerably tough mass, with a variable number of large, dark, colourless or yellowish granules, nuclei, and cells, similar to the epithelial cells already described. It is clear that these contents, which, as I find, contain much fat and protein, differ considerably from the ordinary sweat, which is fluid, and contains no constituents of definite form, and, perhaps, are more nearly related to the sebaceous matter of the skin; and on this account, we might be induced to exclude the glands of the axilla from the class of the sudoriparous glands, and to regard their secretion as peculiar. But these glands also occasionally contain a secretion with but few granules, nay, even nothing but fluid; moreover, there occur, amongst the larger glands of the axilla, smaller ones, which, as regards their contents, come by gradual stages to agree with the *very large glands*, on the one hand, and the ordinary ones on the other. If we further consider that, in exceptional cases, the sudoriparous glands in other places, as, *e.g.*, in the areola of the breast, yield a fluid abundant in granules, and that the ordinary sweat also contains fat and nitrogenous substances, we arrive at the conviction, that a separation of the larger glands of the axilla from the ordinary sudoriparous glands, on account of their secretion is not advisable; and the more so, as we do not as yet by any means know whether the latter may not, under certain circumstances, also contain granules. With regard to the origin of the granular contents, they must be referred to cells which are formed in the gland-tubes. In fact, cells are frequently met with in the latter which contain the same granules as occur free in the canals, and often, so to speak, entirely constitute their contents. It may happen, also, that in one and the same gland the ends of the gland-tubes contain nothing but cells, while the excretory duct contains not a trace of such cells, but only granules and occasional free nuclei; and, in such cases, it is easy to perceive how the cells disappear as they pass upwards, and allow their contained granules and nuclei to become free. These evidently arise from the epithelial cells of the tube of the glandular coil; for, first, the cells of the contents and those of the epithelium are in all respects alike; and, secondly, no epithelium is usually to be found in the glands when their secretion abounds in cells and granules, so that the latter comes into immediate contact with the membrana propria. Now —since, on the other hand, the epithelium may always be very clearly seen in those glands which contain only clear fluid, and frequently includes many dark, pigmentous (even gold-yellow) granules in its cells—it may be assumed, that the cells found in the contents are really cast-off epithelium, and that the secretion, in general, depends upon the continual growth and detachment of epithelial cells.

§ 70. *Sweat-ducts.*—The excretory ducts of the sudoriparous glands, the *sweat-ducts*, or *spiral canals* (fig. 56), commence at the uppermost end of the glandular coil as simple canals, ascend with a slightly serpentine course through the cutis, and then enter the epidermis *between* the papillæ, never at their apices. Arrived here, they begin to become twisted, and, according to the thickness of the epidermis, make from two to sixteen narrower or wider spiral windings, till, at last, they open on the free surface of the epidermis with small, round, frequently funnel-shaped openings, the so-called *sweat-pores*.

The length of the sweat-ducts depends upon the position of the glands and upon the thickness of the skin. The commencement of the duct is, without exception, narrower than the canal in the glandular coil; it measures 0·009‴ to 0·012‴, and remains so until it enters the mucous layer, where it enlarges to double (up to 0·024‴ to 0·028‴) of its former size; thus wide, it passes through the epidermis, and terminates by an opening $\frac{1}{50}$‴ to $\frac{1}{20}$‴ in diameter. In the corium, the sweat-ducts have always a distinct cavity, an outer investment of connective tissue with elongated nuclei (in the glands of the axilla, also, muscles, at least in the lower part), and an epithelial lining of at least two layers of polygonal, nucleated cells, without pigment granules. At the point where the sweat-ducts enter the epidermis they lose their covering of connective tissue, which coalesces with the outermost layer of the corium, and are thenceforth bounded by nothing but layers of cells, which are nucleated in the mucous layer, but without nuclei in the horny layer. Both chemically and structurally, these entirely resemble the cells of the epidermis, excepting only that they are set more perpendicularly, particularly in the horny layer. In the epidermis, the ducts have frequently a distinct cavity; at other times, instead of it, a granular streak extends along the duct, and is probably to be regarded as a secretion, or the sediment of a secretion. The sweat-pores, whose position, in conformity with that of the sudoriparous glands, is sometimes regular, sometimes more irregular, may be seen with the unaided eye on the palm of the hand and sole of the foot; but in other places, can only be recognised with the microscope. Occasionally, the excretory ducts of two glands unite to form one canal (*Krause*).

Fig. 56.

Perpendicular section of the epidermis and external part of the corium of the extremity of the thumb, carried transversely through two ridges. The preparation being treated with acetic acid and seen as magnified 50 times. *a*. Horny layer of the epidermis; *b*. mucous layer; *c*. corium; *d*. simple papilla; *e*. compound papilla; *f*. epithelium of a sweat-duct passing into the mucous layer; *g*. cavity of the same in the corium; *h*. in the horny layer; *i*. sweat-pore.

§ 71. *Development of the Sudoriparous Glands.*—The sudoriparous glands first appear in the fifth month of embryonic life; they are, originally, nothing but *completely solid, somewhat flask-shaped processes of the mucous layer of the epidermis*, and very much resemble the first rudiments of the hair-follicles. In the earliest conditions which I have observed, the processes measured in the sole of the foot 0·03‴ to 0·09‴ in length, 0·01‴ in breadth at the neck, and 0·018‴ to 0·02‴ at the bottom. Even the longest did not extend half-way through the cutis, which was 0·25‴ thick. They consisted, throughout, of round cells, quite resembling those of the mucous layer. Each outgrowth had, in addition, a delicate envelope, which extended to the boundary line of the inner surface of the epidermis. I could find no trace of sweat-pores or sweat-ducts. At the commencement of the sixth month the glands of the palm of the hand and sole of the foot extend to the middle and lower fourth of the cutis; they measure 0·028‴ to 0·04‴ at their swollen end, 0·016‴ to 0·02‴ where the duct ascends from the latter—are already slightly serpentine, and present, at least in their narrower part, a cavity, without, however, penetrating into the epidermis, or opening upon its outer surface. It was not till the seventh month that I found, on the same parts of the body, and then but very indistinctly, the first traces of the sweat-pores and sweat-canals in the epidermis, the latter forming only half a spiral turn. On the other hand, the part of the gland lodged in the cutis was more considerably developed, reached as far as the innermost part of the latter, and was curved like a hook, or already somewhat coiled up at its blind extremity, so as to present the first indication of a glandular coil of about 0·04‴ to 0·06‴ in diameter. The canal arising from it generally made several well-marked spiral turns, and presented a

Fig 27.

A. Sudoriparous gland-rudiments from a seven months' fœtus, 50 times magnified. *a*. Horny layer of the epidermis. *b*. Mucous layer. *c*. Corium. The cavity *e* is fully formed, except that it does not quite reach the thick extremity, which becomes transformed into a glandular coil. The continuations of the ducts into the epidermis; and the sweat-pores, *f*., are present. B. A coil of a sudoriparous gland from a fœtus of eight months.

thickness of 0·015‴ to 0·022‴ and a cavity of 0·003‴ to 0·004‴, which frequently extended even into the terminal coil; it consisted, as well as the latter, of the original but now somewhat thickened membrane, continuous with the surface of the cutis, and of an epithelium composed of several layers of pale, polygonal or rounded cells. In like manner I observed, at this period, the glands on the rest of the surface also, about which, in an earlier stage, I can say nothing, and even those of the axilla differed in no respect from the others. From this period, onwards, the development advances rapidly; the extremity of the gland becomes more and more elongated, rolls itself up, and soon acquires an appearance scarcely differing from that seen in the adult. In newborn infants, the glandular coils in the heel measure 0·06‴ to 0·07‴ (in a child of four months on the heel 0·06‴ to 0·1‴, on the hand 0·12‴) possess much convoluted ducts of 0·015‴ to 0·02‴, and pass, with their excretory ducts (in the cutis 0·008‴ in the rete Malpighii 0·022‴), through the epidermis, in a spiral manner.

From these facts it results, that the sudoriparous glands are not to be regarded as inversions of the skin; and are not from the commencement developed as hollow structures, but first make their appearance as simple outgrowths of the mucous layer. By the continued process of cell-multiplication the original rudiments grow deeper and deeper into the skin, assume their peculiar spiral turns, and become differentiated into the glandular coils and the sweat-ducts; while at the same time a cavity is produced, either by liquefaction of the central portion, which forms, as it were, the first secretion, or by the transudation of fluid between their cells. It is doubtful in what manner the sweat-ducts and sweat-pores in the epidermis are formed; probably it may be by a metamorphosis in the epidermis itself. According to some examinations I have made (*Mikr. Anat.* ii. 1, 171), it appears that a development of sudoriparous glands occurs also after the fifth month, but that at birth the full number is present.

Little is known about the *pathological conditions* of the sudoriparous glands. *Kohlrausch* has found sudoriparous glands of tolerable size (½ a line) in an ovarian cyst, along with hairs and sebaceous glands. In *Elephantiasis Græcorum*, *G. Simon* and *Brücke* observed enlargement of the sudoriparous glands, as also *v. Bärensprung*, in a species of wart; the latter also saw atrophy of the glands in corns, and disappearance of their ducts in the outer layers of the epidermis. The conditions of the glands in old age, in the entire absence of sweat, and in abnormal sweating, is unknown. In a most characteristic case of *ichthyosis congenita* in a new-born infant, which Prof. *H. Müller* and I examined, the sudoriparous glands were present. Their excretory ducts, in their course through the epidermis, which reached two lines in thickness, partly presented the usual arrangement, and were partly, as on the sole of the foot, disposed, almost quite horizontally, in their outer portions, some of them running thus for the space of 1½ lines, so that in horizontal sections of the epidermis they appeared, at first sight, as entirely abnormal, horizontal canals, with a cavity 0·0015‴ to 0·003‴ in diameter. The contents of the sweat-ducts were peculiar, and consisted, without exception, of numerous white fat globules. I also observed sweat-glands in the case described by *Mohr* of a large cavity in the lungs containing hairs; they measured as much as 0·24‴ in diameter, and were seated in a *panniculus adiposus*, furnished with the ordinary fat-cells. It may be remarked that the walls of the cavity, in addition to the above-mentioned fatty layer, also possessed a corium with papillæ and an epidermis, like the external skin.

Method of examination. In order to examine the position of the sudoriparous glands and their excretory ducts, fine sections of the fresh or slightly dried skin of the palm of the hand or sole of the foot should be prepared, and made transparent by adding acetic acid or caustic soda. In macerated portions of skin the cellular linings of the sudoriparous glands, with their investment of connective tissue, can be pulled out from the cutis, along with the epidermis, in the form of long tubes. I have not unfrequently succeeded in so obtaining them in delicate parts of skin after moistening with concentrated acetic acid. The examination of the glandular coils is very easy in the glands of the axilla; in other places the skin must be dissected from within, and the glands must be sought for, partly on the inner surface of the cutis, partly in its meshes, which with some attention may be easily done with success, especially on the hand, foot, and nipple. The large glands of the ball of the foot of the dog, which *Gurlt* described, are particularly well adapted for demonstration; and still more suitable are the large glands of the prepuce of the horse, and of the skin of the udder of the mare, which lie quite loose in the subcutaneous tissue. In order to study the development of the glands, sections of the fresh or dried skin of the heel and palm of the embryo should be made; in embryos which have been preserved in spirit, the glands can still be very well seen, if the sections are fine; this is especially the case immediately after the action of caustic soda.

Literature.—Breschet et Roussel De Vauzème, in *Annal. d. Scienc. Nat.* 1834, pp. 167, 321; Gurlt in Müll. *Arch.* 1835, p. 399; Tobien, *De Glandularum Ductib. efferent.* Dorp. 1853, p. 8.

B.—OF THE CERUMINOUS GLANDS OF THE EAR.

§ 72. The ceruminous glands of the ear are simple glands, of a brownish colour, entirely resembling the sudoriparous glands in external aspect, which exist in the external auditory meatus, but not in its whole extent, being confined to its cartilaginous portion. They lie here between the skin lining the passage and the cartilage, or the fibrous substance which supplies its place, in a dense, subcutaneous cellular tissue, with little fat; and form a continuous yellowish-brown glandular layer, easily visible to the naked eye. This layer is thickest in the inner half of the cartilaginous meatus, and becomes gradually thinner and looser towards the orifice, but is quite equal in extent to the cartilaginous meatus itself.

The ceruminous glands may each be divided into the glandular coil and the excretory duct. The former (fig. 58) of $\frac{1}{10}'''$ to $\frac{1}{4}'''$ to $\frac{3}{4}'''$ in diameter, consists of several coils of a single canal of 0·03''' to 0·06''' on an average 0·04''' to 0·05''' ($\frac{1}{20}$th''' to $\frac{1}{25}$th''') thick, which here and there, but not constantly, presents small saccular protrusions and terminates by a blind, slightly swollen extremity. A short, straight, excretory duct of 0·017''' to 0·024''' in diameter, ascends from the coil, penetrates the corium and epidermis of the auditory passage, and generally opens separately by a round pore of 0·044''' in diameter, or terminates on the upper part of a hair-follicle.

Fig. 58.

Section through the skin of the external auditory meatus, magnified twenty times. *a.* corium; *b.* stratum Malpighii; *c.* horny layer of the epidermis; *d.* coils of the ceruminous glands; *e.* excretory duct of the same; *f.* their openings; *g.* hair-follicles; *h.* sebaceous glands of the auditory meatus; *i.* small collections of fat.

In their intimate structure the ceruminous glands are constituted as follows:—The tube of the glandular coil possesses a fibrous coat and an epithelium, the former 0·004''' to 0·005''' in thickness, the latter 0·004'''. The fibrous coat presents exactly the same characters as that of the larger sudoriparous glands, *i.e.* it consists of an internal layer of smooth muscular tissue, disposed longitudinally, of 0·0023''' to 0·0026''' in thickness, and of an external layer of connective tissue with scattered nuclei and occasional very fine transverse elastic fibres. The epithelium lies probably upon a *membrana propria*, and consists of a simple layer of polygonal cells of 0·006''' to 0·01''' in diameter, which contain yellow-brown pigment granules, varying from immeasurable minuteness to 0·002''' and insoluble in alkalies and acids in the cold, or whitish fat-drops measuring as high as 0·001'''; and, it is to be observed, that for considerable lengths of a gland-tube the epithelium-cells contain only one and the same kind of granules; so that the glands appear either uniformly brownish, or of dark colour, but in the latter case whitish by reflected light. The contents of the glandular canals are sometimes a clear fluid, sometimes a *granular substance*, consisting principally of cells, similar to those of the epithelium; whence it would seem that their secretion is produced in the same mode as that of the sudoriparous glands. The excretory ducts possess a coat of connective tissue, and an epithelium of several layers, formed of small, nucleated cells, destitute of fat and pigment granules. In their cavity, which, however, is not always distinct, the ducts contain sometimes a clear fluid, sometimes a small quantity of a finely granular substance.

The cerumen is generally regarded as the secretion of these glands, though this is only partially correct. If the wine-yellow or brownish, more or less consistent, viscid substance, which collects in the cartilaginous meatus, be examined, it is found that it is composed of various constituents. Besides a few hairs, an occasional *acarus folliculorum*, and a variable number of epidermis cells, we meet with, 1st. numerous cells of 0·009‴ to 0·02‴ in diameter, entirely filled with pale fat, and generally of an oblong, flat, irregular shape, in which, on the addition of water, or, still better, of caustic soda, the fat collects in separate, round or irregular, dark drops; 2nd. much free fat in the form of pale, yellowish small, rounded drops, which, on the addition of water, become very distinct, although, at the same time, decolorized, and appear as round, dark granules, from immeasurable fineness up to 0·002‴, and more, in diameter; 3rd. yellow, or brownish granules, and aggregations of granules, either free or in cells, which, upon the whole, are but few in number; 4th. finally, when the secretion is more diffluent, also a small quantity of a clear fluid. I regard the first-mentioned cells as belonging to the cutaneous fatty secretion of the external auditory passage, and the other matters as the secretion of the ceruminous glands, which, accordingly, would appear to secrete a fluid rich in fat, with a few brownish granules.

The vessels of the ceruminous glands resemble those of the sudoriparous glands. In one case, I also observed a fine nerve-fibre 0·003‴ in diameter, in the midst of a gland. The development takes place in exactly the same manner as that of the sudoriparous glands; and, indeed, from all that I have observed of them, I am induced to regard the ceruminous glands as merely modifications of the sudoriparous glands.

Nothing is known about their pathological conditions. Of the *cerumen*, we know that it is frequently very firm, at other times fluid, purulent-like, and pale-coloured. In the latter case, which occurs in congestive states of the auditory passage, it contains much more fluid and free fat than usual, and very beautiful cells containing fat.

C.—OF THE SEBACEOUS GLANDS.

§ 73. These are small, whitish glands, which are found over almost the whole extent of the skin, and yield its fatty secretion, *sebum cutaneum*. Their form is very various. The simplest (fig. 59A) are pyriform or short tubular pouches; in others—*the simple racemose*—two, three, or even more follicles or saccules, are united by a shorter or longer pedicle; in others, again (figs. 59B and 60), two, three, or more clusters of saccules are connected by a common duct, and form a *compound racemose gland*. Besides these three forms, which represent only the chief varieties, there are various intermediate forms, which do not require a detailed description.

Fig. 59

Sebaceous glands from the nose, magnified about 50 times. A. Simple tubular gland without hair. B. Compound gland, opening in common with a hair-follicle. *a.* glandular epithelium, continuous with *b.* the mucous layer of the epidermis: *c.* contents of the glands, sebaceous and free fat cells; *d.* the separate racemes of the compound glands; *e.* hair follicle (root-sheath) with the hair *f.*

The sebaceous glands principally occur in parts covered with hair, and open on the surface in conjunction with the hair-follicles; on which account they have also been termed *glands* of the hair-follicles. In all the coarser hairs, the glands appear as lateral appendages of the hair-follicles, and open into the latter by narrow excretory ducts (fig. 59B). In woolly hairs, on the other hand, the gland-ducts and the hair-follicles are either nearly equally large, and open into a common canal, which may, with equal reason, be regarded as a continuation of the one or of the other; or the glandular canals preponderate (fig. 60) and the hairs pass into a subordinate relation, so that their follicles terminate in the glands, or even open at the orifice of the glands.

In places destitute of hair, sebaceous glands are found only in the *labia minora*, the glans and prepuce of the penis, but are not present on the glans and prepuce of the clitoris. In general the glands lie close to the hair-follicles in the more superficial part of the cutis, and are larger in connection with small than with large hairs; but they present many individual differences. The glands of the larger hair-follicles are generally simple racemose glands, having an average diameter of $\frac{1}{10}'''$ to $\frac{2}{10}'''$, and are disposed to the number of 2 to 5 around the follicles. The smallest, of 0·1''' to 0·16''' in diameter, are found in pairs, connected with the hairs of the scalp; larger ones, of 0·16''' to 0·24''', in the hairs of the beard and the longer hairs of the chest and axilla, in which they are generally placed in groups around the follicles; the largest on the *mons veneris*, the *labia majora*, and the *scrotum*. In all these places, at least in the last-mentioned, they are situate at the inferior boundary of the cutis, and being connected in clusters of from 4 to 8, form beautiful rosettes of $\frac{1}{4}$, $\frac{1}{2}$, to 1''' broad. The smaller sebaceous glands, connected with the follicles of small stout hairs, as on the eyebrows, eyelids, and entrance of the nostrils, are, as I find, generally disposed in pairs of 0·06''' to 0·24''' in diameter. Larger glands, or collections of glands of $\frac{3}{4}'''$ to 1''' in diameter, are generally found connected with the downy hairs—the most beautiful upon the nose, the ear (*concha, fossa scaphoidea*, etc.), penis (anterior half), and *areola* of the nipple; but particularly upon the part first mentioned, where the glands often assume a colossal size and very singular forms (fig. 60). On the *caruncula lacrymalis*, the glands are generally of $\frac{1}{8}'''$ to $\frac{1}{3}'''$ in diameter; on the lips, forehead, chest, and abdomen, they are somewhat smaller, yet generally larger than those of the hairy scalp, the eyelids, cheeks, neck, back, and extremities. Of sebaceous glands unconnected with hair-follicles, only a part of those on the *labia minora* are of considerable size (0·14''' to 0·5'''), rosette-shaped, and with apertures of 0·033''' in diameter; the others are generally simply tubular, and at most 0·12''' to 0·16''' long, and 0·04''' to 0·06''' broad. The terminal saccules of the sebaceous glands are either round, pyriform,

Fig. 60.

Very large gland from the nose, with a small hair-follicle opening into it; magnified 50 times. The letters *a.* to *f.* as in fig. 59.

or flask-shaped, or even elongated and tubular. Their size varies extremely, from 0·06‴ to 0·16‴ in length, 0·02‴ to 0·1‴ in breadth; it amounts, on an average, in the round ones, to 0·04‴, and in the others to 0·08‴ in length, and 0·03‴ in breadth. Their excretory ducts are likewise of very various dimensions — long or short, wide or narrow; the principal excretory ducts measure in the nose and *labia minora* up to $\frac{1}{3}$‴ in length, $\frac{1}{15}$‴ to $\frac{1}{6}$‴ in breadth, and possess an epithelium 0·015‴ to 0·03‴ thick.

The Meibomian glands of the eyelids, whose description will be given with that of the eye, resemble the sebaceous glands in all essential points, except that they are larger.

§ 74. The *minute structure* of the sebaceous glands is as follows. Every gland has an outer delicate envelope of connective tissue, which proceeds from the hair-follicle, or in the case of independent glands, from the corium; within are masses of cells, which are continued from the outer root-sheath of the hair-follicle, and form a lining of rounded or polygonal, nucleated cells, disposed in several (2 to 6) layers. In the glandular saccules themselves, these cells generally contain a little fat, and form a simple layer, but gradually pass into cells which are so filled with colourless fat, that they might be fitly termed *sebaceous cells* (fig. 61). Their fat appears either in the form of small discrete drops (*b b*), or, as is more common, in larger drops (*c*); in many cells, indeed, there are only a few, or even but one single drop entirely filling them, so that they offer a great resemblance to fat-cells of the panniculus adiposus. If these innermost cells, in which nuclei can be but rarely discovered, be followed towards the excretory ducts, nothing is easier than to observe that similar cells, in uninterrupted succession, are continued into the ducts — that is, into

Fig. 61.

A. A glandular vesicle of an ordinary sebaceous gland, magnified 250 times. *a*. Epithelium sharply defined, but without being invested by a *membrana propria*, and passing continuously into the fat-cells in the interior of the gland-tube (the contents are rather indistinctly represented). B. Sebaceous cells from the gland-tubes, and the sebaceous matter, magnified 350 times. *a*. Smaller nucleated cells, containing but little fat, and possessing more the character of epithelium; *b*. cells abounding in fat, without visible nuclei; *c*. cells, in which the fat-particles are beginning to run together; *d*. cell with one fat-drop; *e*. *f*., cells whose fat has partly disappeared.

the excretory canals lined with epithelium — then enter the hair-follicle, where they occupy the space between the hair and epidermis of the hair-follicle, and are, finally, discharged externally. These cells alone form the sebaceous matter of the skin. This is, at the temperature of the living body, a semi-fluid substance, but in the dead subject, has more of a cheesy consistence; by the addition of dilute alkalies, it can be easily shown to consist of cells. Besides the sebaceous cells, the sebaceous matter of the skin also contains free fat.

According to the above remarks, the sebaceous matter of the skin is a secretion, which may be said to consist solely of distinct particles, namely, cells containing fat, or such cells intermixed with fat-drops. These cells are developed in the vesicular extremities of the glands by a process of cell-formation, depending entirely, as in epidermic structures generally, on pre-existing cells, and without free cell-formation, of which in this case there is not the slightest evidence. The free fat in the sebaceous matter of the skin arises from the bursting of the sebaceous cells, and perhaps, also, by transudation through the cell-wall. So considered, the formation of the sebaceous matter of the skin resembles, in many respects, the production of the epidermis. The young and readily soluble cells at the bottom of the glandular vesicles may be compared to the Malpighian cells of the epidermis, and the less soluble ones, filled with fat, to the horny plates. This comparison will appear the more apt, when it is remembered, 1. that the deep layer of the epidermis of the hair-follicle is continued uninterruptedly into the gland-ducts and the outermost cells of the terminal vesicles; and 2. that the epidermis also forms in some places a secretion, by continual detachment of its cells (I refer to the *smegma præputii penis et clitoridis*), and also yields substances which, to all appearance, are chemically allied to sebaceous matter.

I have not observed nerves on the sebaceous glands; but fine *vessels*, and even *capillaries*, are found around the larger glands, especially those of the penis and scrotum, and ear. I may again refer to the smooth muscles, described when speaking of the corium as situate in the neighbourhood of the sebaceous glands, whose contraction can scarcely be unconcerned in the evacuation of the secretion.

§ 75. *Development.*—The formation of the sebaceous glands takes place at the end of the fourth and in the fifth month, and is most intimately connected with the development of the hair-follicles, inasmuch as they appear contemporaneously with the commencing hairs, or, a short time after, as *outgrowths of the outer root sheath* (fig. 52). These are, at first, from 0·02‴ to 0·03‴ in diameter, and from 0·01‴ to 0·016‴ in thickness, but soon become larger and pyriform, or flask-shaped. Fat is then developed in the inner cells, till at last the fat-cells extend as far as the canal of the hair-follicle. The gland and its contents are now formed, and a multiplication of the cells at the bottom of the gland, or in the gland-vesicle, is all that is requisite to push the sebaceous cells of the duct into the hair-follicle, and fully establish the secretion. Accordingly, the sebaceous, like the sudoriparous glands, are, at first, solid outgrowths of the Malpighian layer of the skin, which subsequently acquire external orifices, and the first sebaceous matter of the skin is formed by a metamorphosis of the inner cells of the glandular rudiments; whilst the space which these cells occupy becomes the cavity of the gland, which, however, never appears hollow, but is kept filled by the continual advance of the growing cells.

The above-described development of the sebaceous follicles takes place rather rapidly. In the fifth month, the secretion commences in many places; and in the sixth, it is everywhere fully established. It is further to be remarked, that besides the original glands, which are attached singly or in pairs to a hair-follicle, in the sixth month *new rudiments* arise, which generally have a deeper position; and after going through the above-described process of development, assume the form of secreting glands.

In the further development of the sebaceous glands, the originally simple gland-tube puts forth solid buds by the growth of its external fatless cells, which buds are gradually transformed into glandular vesicles in exactly the same manner as the first rudiments. By repeated budding of the primitive or secondary glandular vesicles, the larger clusters are formed, and from these, finally, the most complex that appear. In the fœtus of the seventh month, the majority of the glands are still simple pedunculated tubes of 0·04‴ to 0·06‴ in length, and 0·02‴ to 0·03‴ in breadth, which

Fig. 62.

Development of a sebaceous gland in a six months' fœtus. *a*, Hair; *b*, inner root-sheath; *c*, outer root-sheath; *d*, rudiment of a gland, with fat developed in the central cells. Magnified 250 times.

are placed singly or in pairs on the hair-follicles. In the new-born infant, simple clusters, of 0·1‴ to 0·12‴ in length, and only 0·04‴ to 0·06‴ in breadth, and disposed singly, or more rarely in pairs, upon the follicle, are found in place of the simple tubes. It is only on the chest, ear, temples, nose, nipple, the *labia majora*, and the *scrotum*, that they are rosette-shaped; they here measure 0·1‴ in diameter, and, in the four last-mentioned places, even up to 0·4‴ and more. From these statements, it appears that most of the glands continue to increase after birth; certain glands are only developed after birth, as, for example, those of the *labia minora*.

The sebaceous glands occur also in abnormal positions. Thus *Kohlrausch* observed them in an ovarian cyst, and *v. Bärensprung* in a subcutaneous encysted tumour of the forehead; and in both places they were associated with hair-follicles; whence it may be concluded, that they are, perhaps, often present in cysts which contain hairs. In fact, I met with very beautiful sebaceous glands, with much sebaceous matter in the walls of the before-mentioned hair-containing cyst in the lungs. *V. Bärensprung* believes he has seen, though rarely, a new formation of the sebaceous glands in cicatrices of several years' standing. When the hairs fall out, the sebaceous glands seem to disappear; at least, I have frequently noticed that they were wanting in bald spots. According to *E. H. Weber*, hypertrophy of the sebaceous glands takes place in cancer of the skin; according to *v. Bärensprung*, in *akrothymion*, or moist warts, and in *nævus pilosus*. The *comedones*, also, among which I rank the *lichen pilaris*, at least, as defined by *Simon*, are hair-follicles and sebaceous glands, filled with and dilated by sebaceous matter. They especially occur in places where the glands are distinguished for their size, as on the nose, lips, chin, ear, areola of the nipple, and the scrotum, and arise either from obstruction of the openings of the hair-follicles by sordes, or from viscidity and tenacity of the secretion. They contain—besides one or several hairs, which, however, may also be absent—fat-cells, as in the normal sebaceous matter, epidermis-cells from the hair-follicles, free fat, frequently crystals of cholesterine and the *acarus folliculorum*.

Milium. The small white spots or nodules termed *milium*, found on the eyelids, the root of the nose, the scrotum and ear, are likewise formed, as *v. Bärensprung* justly assumes, from the sebaceous glands; that is, when the latter alone, without the hair-follicles, dilate, whence rounded prominent nodules, without any aperture, are produced, with contents resembling those of the comedones, which may frequently be pressed out through the hair-follicles. Lastly, the sebaceous cysts, which have their seat in the cutis itself, must undoubtedly be regarded as enormously enlarged hair-follicles, with the sebaceous glands. For particulars concerning these, we refer the reader to the works already cited; also, with regard to a small parasite, the *acarus folliculorum*, which inhabits both healthy and enlarged hair-follicles and sebaceous glands, *G. Simon* (l. c., p. 287) may be consulted. In the before-mentioned case of *ichthyosis congenita*, *Dr. H. Müller* and I found the excretory ducts of the sebaceous follicles in the epidermis everywhere enlarged, of 0·03‴ to 0·06‴

in diameter, with saccular dilatations of 0·04''' to 0·12''' in diameter, which were often arranged in groups behind each other, and wholly filled with sebaceous matter. Occasionally a small hair lay in such a duct, so that the latter appeared at the same time as a hair-follicle.

In investigating the sebaceous glands, they may be dissected either from within and separated with their hair-follicles from the skin, or perpendicular sections of the skin may be made, which, however, should not be too fine. The minute structure of the glands having been studied in those of the *scrotum*, *penis*, or *labia minora*, which can be isolated without trouble, and are, therefore, the best to begin with,—especially with the aid of acetic acid, which renders the surrounding parts transparent—the investigation of those of other parts, which concerns chiefly their form, size, and position, will be most facilitated by the use of alkalies, especially caustic soda, which readily clear up the tissues that obstruct the view of the glands; whilst the latter, in consequence of their fatty contents, are but little affected. Should it be desired to study not so much the coverings as the cells of the glands, and, at the same time, to obtain a general view of their form, there is no better plan than to macerate the skin, after which the hairs with their root-sheaths, and the cell-masses of the sebaceous glands, epithelium, and contents, may be often stripped off *in toto* with the epidermis. The same end may be attained more speedily where the epidermis is thin (*scrotum*, *labia majora*, *glans penis*), by dropping concentrated acetic acid upon it, or by means of soda, although more of the cells of the glands are destroyed in this way. The maceration of the fœtal skin, and the rendering it transparent by acetic acid, are of great use in studying its development. The fat-cells in the interior of the glands are quite easily isolated by teasing out a good-sized gland. The excreted secretion may be examined both by itself, and with the addition of water and caustic soda.

Literature.—See the treatises cited under the section on the skin; of GURLT (p. 409), KRAUSE (p. 126), G. SIMON (p. 9), VALENTIN (p. 758). Also the general histological works by TODD and BOWMAN (p. 424, fig. 92), SHARPEY, HASSAL (pl. liv. should be pl. liii., p. 401), GERBER (p. 75, figs. 40, 42, 43, 44, 45, 239), the drawings by WAGNER (*Icon. Phys.*, tab. xvi. fig. 11, *e.*), ARNOLD (*Icon. Anatom. Fasc.*, ii. tab. xi. fig. 10), and BERRES (tab. xxiv.), in addition, G. SIMON, in MÜLL. *Arch.*, 1844, p. 1.

OF THE MUSCULAR SYSTEM.

§ 76. To the muscular system belong all the *transversely-striped muscles*, which, together with their accessory organs, the tendons and fasciæ, serve for the movement of the skeleton, the proper organs of the senses and the skin. They are situate between the skin and the bones, and between the bones themselves; and are so associated and connected by common investments, that the whole may be rightly regarded as constituting one system.

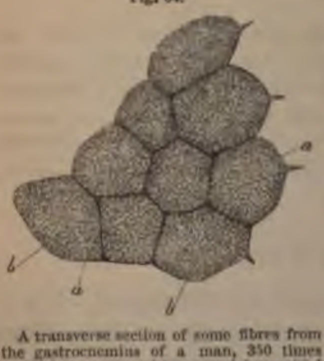
§ 77. The proper elements of the muscles in question, still perceptible to the naked eye,—the *transversely-striped* (animal or voluntary) *muscular fibres*, or *primitive bundles* (fig. 25)—are especially distinguished by their thickness and the definite character of their component parts from the most of the transversely-striped muscular fibres occurring in other situations. With respect to the latter distinction; the *sheath of the primitive bundles*, or the *sarcolemma*, is to be recognised with facility in all bundles without exception, particularly after the addition of water, acetic acid, and alkalies, and also by maceration in diluted hydrochloric acid (*Donders, Lehmann*), as a wholly structureless, transparent, elastic, smooth investment, which, in man, as well as in mammalia, is distinguished by its delicacy from the same part in the lower vertebrate animals, especially the naked amphibia.

Fig. 63.

Primitive fibrils from a fibre, or primitive fasciculus, of the *Axolotl* (*Siredon pisciformis*); 600 times magnified. *a*. a small bundle; *b*. an isolated fibril.

The *muscular fibrils*, or *primitive fibrillæ*, which are closely invested by the sarcolemma, may be isolated in muscles which have been macerated, or boiled, or preserved in alcohol or chromic acid. They are generally *varicose*,—*i. e.*, marked at intervals of 0·0004‴ to 0·001‴, with smaller or larger swellings; and, as their thicker and thinner places correspond in position throughout the whole thickness of the fibre, the latter, for the most part, presents an elegant transversely-striated aspect; but, here and there, also a few fine longitudinal striæ; more rarely, from the varicosities being faintly or not at all expressed, the fibre may exhibit only a longitudinal striation. In the adult, the fibrillæ do not surround a central cavity or canal, but form (fig. 64), with the scanty intermediate connecting substance, perfectly compact fasciculi. On the inner surface of the sarcolemma, numerous lenticular, or spindle-shaped nuclei, are constantly found, of 0·003‴ to 0·005‴ in length, and frequently furnished with nucleoli. These nuclei are not disposed with any regularity: sometimes two or more at one level, or

Fig. 64.



A transverse section of some fibres from the gastrocnemius of a man, 350 times magnified. *a*. sarcolemma and interstitial connective tissue; *b*. section of the fibre itself, showing many fatty granules imbedded in the interstices between the fibrils.

in rows, or alternately one behind the other. Besides, very minute and pale granules (the interstitial granules as I have called them) are always met with around the nuclei and between the fibrillæ, in regular rows, which, in abnormal muscular fibres, are transformed into the well-known fat and pigment globules (fig. 64).

The form of the muscular fibres is rounded-polygonal. In diameter they vary from 0·005‴ to 0·03‴, and more. In the trunk and extremities, they are, without exception, thicker (0·016‴ to 0·03‴) than on the head, in which situation the muscles, especially those of the face, are distinguished by the smallness of their fibres (0·005‴ to 0·016‴). It is to be observed, however, that great differences often prevail, in this respect, in one and the same muscle. As far as is known, there is no absolute difference in the thickness of the muscular fibres in men and women, or in weak and robust individuals. On the other hand, it is possible that in one case the one extreme, and in another the other, may prevail. The thickness of the primitive fibrils in man amounts, on an average, to 0·0005‴: their number in a fibre must, in the thicker ones, amount to several hundreds, but it is not known with certainty.

Various controversial opinions still prevail, as regards the composition of the muscular fibres. Several authors, above all, *Bowman*, are of opinion, or at least consider it as probable, that the fibrils are artificial products. According to the last-named author, a breaking up of the muscular fibres into *discs* (fig. 65) is quite as natural, although not quite so frequent, as that into fibrils; and they may with equal justice be held to be columns of discs, as bundles of fibrils. Were a muscular fibre broken up in the direction of both the transverse and longitudinal striæ, small, roundish-angular particles would be produced, which might be designated primitive particles, or *sarcous elements*. In the muscular fibre, these elementary particles are united in the transverse, as well as the longitudinal direction, and form, in the one case a disc, in the other, a section or joint of the fibrillæ. The breaking up into discs could, in my opinion, be considered of importance only if it occurred as frequently as that into fibrils and also took place occasionally in fresh muscles. But nothing of the sort is to be seen in the fresh muscles of man and the higher animals. It is rare, even, in macerated fasciculi; while, on the other hand, the fibrils can be isolated in almost every muscle, by any one moderately conversant with the matter.

In *transverse sections of fresh-dried or fresh muscles of the frog*, the transverse sections of the fibrillæ can be distinctly seen, which fact refutes all those opinions according to which the muscular fibres, during life, consist of a homogeneous, solid or fluid substance. Moreover, it may be remarked, that the assumed elementary particles can only be isolated with difficulty, except in macerated muscles, where their separation is undoubtedly easy; and also, that in the perfectly fresh muscles of certain insects (*coleoptera*, *neuroptera*, *hymenoptera*, *lepidoptera*, *diptera*, *orthoptera* in part, *hemiptera* in part), the individual fibrils can be very beautifully separated. Considering the great similarity between the muscles of insects and those of the higher animals, in all other essential points, the above fact appears to me to be very striking. I am, therefore, for this and the other reasons assigned, fully convinced of the existence of fibrils during life, and believe that, in man and many animals where they cannot be so easily isolated, they are held together by an intermediate substance, and, in fact, so firmly, that, under certain circumstances, fissures may take place across the fibres, *i. e.*, in the direction of the thinner parts of the fibrils.

Fig. 65.

A. a muscular fibre, or primitive fasciculus, breaking up in the transverse direction, into discs, 350 times magnified. It exhibits distinct transverse and fainter longitudinal striæ. The discs, of which B. represents one more magnified, are granulated, and consist of the sarcous elements of Bowman, or, according to other authors, of small pieces of the fibrils. After Bowman.

I consider the sarcous elements as artificial products, occasioned by the breaking up of the fibrils at the parts where they are thinner, which naturally takes place much easier there than elsewhere. I refrain from giving an opinion as to the nature of these particles, as I hold that our microscopes do not afford adequate data for forming a sure judgment respecting elements of such fineness.

§ 78. The muscular fibres, in the trunk and extremities, are generally so connected, that, without dividing and reticularly uniting, but terminating not unfrequently here and there in the interior of the muscles with pointed extremities (*Rollet*), they lie parallel to each other in prismatic bundles, extending the whole length of the muscle. Each of these so-called *secondary fasciculi* is enclosed by a special investment of connective tissue. Several of these are united by stronger investments, to form *tertiary fasciculi;* while, finally, a greater or smaller number of these last combine to form the bellies of the muscles and muscles themselves.

Fig. 66.

Transverse section from the sterno-mastoid in man, 50 times magnified. *a*. external perimysium; *b*. internal perimysium; *c*. primitive and secondary fasciculi.

The *muscular fasciculi* may be so arranged as to give rise to membraniform muscles, which are extended in the superficial dimension; or they may form the oblong or fascicular muscles, in which they are collected into thicker masses. Accordingly, the muscles are aggregations of many larger and smaller *secondary* and *tertiary* bundles, whose sheaths *form a connected system*, the *perimysium*, of which the part externally surrounding the entire muscle is distinguished as *perimysium externum*, or the muscular sheath, strictly so called, from the portion immediately inclosing the larger and smaller bundles, and the muscular fibres—the *perimysium internum*. The thickness of the secondary muscular bundles varies from $\frac{1}{5}'''$ to $\frac{1}{2}'''$; that of the tertiary, and still larger bundles, which are most obvious in muscles of apparently coarse texture (*glutæus maximus*, *deltoideus*), is so variable, and the division of these larger constituents of a muscle so arbitrary, that there is nothing specially to be said concerning them. The perimysium consists of ordinary *connective tissue*, and *fine elastic fibres*. In all muscles, especially in those of lax structure, fat-cells often occur in large numbers in the perimysium.

§ 79. *Connection of the Muscles with other parts.*—The muscular fibres are connected with the moveable structures, the bones, cartilages, articular capsules, the skin, etc., either immediately or by the interposition of fibrous parts, such as tendons, aponeuroses, certain portions of muscular fasciæ and ligaments. Those muscles, which are entirely, or only at one extremity attached without the intervention of tendons, constitute, upon the whole, the minority. Where muscular fibres arise immediately from bone (*obliqui*, *iliacus*, *psoas*, *glutæi*, etc.) or from cartilage (*transversus abdominis*, *diaphragma*), or are immediately inserted into these parts (*serrati*, *omo-hyoideus*, *sterno-hyoideus*, muscles of the ear), they proceed only as far as the periosteum or perichondrium, and terminate with blunt extremities upon these membranes, into whose fibres they are not continued, nor do they come into immediate contact with the bones and cartilages. When muscles extend to the skin, they either lie flat underneath it without any direct connection, or spread out in its substance in form of larger and smaller bundles (muscles of the face), and appear to be attached to its bundles of connective tissue; as has been observed in the *levator labii superioris* of the rat, by *Busk* and *Huxley*.

§ 80. The *tendons* are glistening, white, or yellowish structures, almost entirely composed of connective tissue. They are divided, according to their form, into the *funicular*, or *proper tendons*, and the *membranous aponeuroses* (*centrum tendineum*, *galea cranii*, tendons of the abdominal muscles, *latissimus*, *cucullaris*, etc.). These two forms—not strictly separated by external characters—

agree in all essential points of intimate structure. They consist of connective tissue, which is characterised by the parallel course and firm union of its elements, and its poverty in elastic fibres. The elements of the connective tissue, the *fibrils*, can be easily seen in fresh tendons, as well as in transverse sections of dried specimens, where, as in other parts of the body, they are very fine. In funicular tendons, they have a beautiful undulating course, parallel to the long axis of the tendon; and, in the fresh condition, cohere so firmly, that the primitive bundles are with difficulty demonstrated. But such fasciculi, 0·006‴ to 0·008‴ broad, and of rounded polygonal form, do actually exist, as may be seen in transverse sections of dried tendons, particularly after the addition of alkalies. In the natural condition, they are so intimately united with each other, that they cannot be isolated. On the other hand, secondary and tertiary bundles are very distinct even in fresh tendons. Thin partitions of loose connective tissue extend through the tendinous tissue, and, being all connected with each other into a continuous system of parallel tubes, separate the tendinous fasciculi into numerous larger and smaller groups. Secondary bundles, mostly of a polygonal, but also of a rounded or elongated form, and of 0·03‴ to 0·05‴ in diameter, may be very clearly distinguished; also tertiary bundles with polygonal contours of 0·1‴ to 0·5‴ and more in thickness, and bounded by somewhat thicker partitions. For the most part, also, there are still larger divisions, which are composed of numerous tertiary bundles, and which, firmly connected in very various numbers and groups, and surrounded by a common envelope of lax connective tissue, constitute the tendons themselves.

The *aponeuroses* have either the same composition as the proper tendons, and consist of several layers of parallel secondary bundles, disposed in the same plane, or they more resemble the fibrous membranes, and exhibit primary and secondary bundles decussating in two or more directions (abdominal muscles, diaphragm).

In the secondary bundles of all tendons, there are *fine elastic fibres* in various stages of development; sometimes as rows of narrow, spindle-shaped cells, connected by slender prolongations; sometimes as fully-developed fibres of uniform breadth, or as isolated fusiform cells. The arrangement of these elements is everywhere the same; they run at regular distances parallel to and between the tendinous fasciculi; so that in transverse sections of the tendons the dark ends of the elastic fibres are seen distributed over the whole area, at distances of 0·007‴ to 0·008‴. Besides these stronger elastic fibres, which measure from 0·0005‴ to 0·001″ in diameter, there are in most, perhaps in all tendons, other very fine fibrils of 0·0002‴ and 0·0004‴ in diameter, which connect the former in various ways; so that, in every tendon, a real network of elastic tissue penetrates and entwines the bundles of connective tissue. In transverse sections, these fibrils may also be distinguished as fine dark points, or as fine lines radiating from larger spots (fig. 67); they are still more distinct in longitudinal sections, in which the fibrous system in question can generally be very well perceived. Such sections show, also, that wherever the formative cells of the fibres still possess a certain degree of independence, beautiful elongated nuclei exist in them. Besides these elastic fibres, the tendons contain, in certain places, cartilage-cells (see below); also ordinary *fat-cells*, especially in the less compact tendons, as in the tendinous stripes of the intercostal muscles, *triangularis sterni*, *masseter*, etc.

Fig. 67.

Tendon of the human *tibialis posticus*, magnified 60 times. *a*. Secondary bundles; *b*. larger elastic fibres; *c*. interstitial connective tissue. The minute dark points represent the finest elastic fibres.

Fig. 68.

a. A Muscular fibre from a human *intercostalis internus*, passing continuously into a tendinous bundle *b*.; magnified 350 times.

The transversely-banded appearance of the tendons, which occasions their glistening aspect, depends simply upon undulating flexures of their fibrils, which run parallel to each other through the whole bundle. This appearance vanishes, when they are strongly stretched, and is only the expression of their inherent elasticity which presents itself in the relaxed condition.

§ 81. *Connections of the Tendons with other parts.*—The tendons are connected, on the one hand, with the muscles, and, on the other, with the various parts moved by the latter. Even with the naked eye, it may be seen that in the former connection, either the tendon and muscle are continued into each other rectilinearly, without any distinct line of demarcation (*fig. 68*), or the muscular fibres, with rounded extremities, and closed sarcolemma, abut on the borders and surfaces of the tendons and aponeuroses at an acute angle, as seen in penniform muscles. In this case the extremities of the fibres dip into small depressions on the surface of the tendon, whilst the connective tissue between them (*perimysium internum*) passes continuously into that of the tendons. This latter arrangement is found wherever muscular fibres and tendons meet at an oblique angle, consequently in all the penniform and semi-penniform muscles, in those whose tendons of attachment commence in a membranous form (*soleus*, *gastrocnemius*) and those which arise from the surfaces of fasciæ, bones and cartilages. Where, on the other hand, the fibres of aponeuroses and tendons meet those of muscles rectilinearly, a real transition of tendinous fasciculi into muscular fibres for the most part occurs, although not always, for in apparent rectilinear transition of muscles into tendons, an oblique attachment of the former with free extremities, although under very acute angles, is also frequently found, and particularly where tendons penetrate deeply into the muscular substance, and divide into separate bundles.

The tendons are also connected with bones, cartilages, fibrous membranes (*sclerotica*, *vagina nervi optici*, tendinous fasciæ), ligaments, and synovial membranes (*subcruralis*, for instance). With the first-mentioned parts the connection takes place either by the intervention of the periosteum and perichondrium, and therefore indirectly—the tendinous fibres mostly passing into the similarly constituted elements of these investments, or appearing to strengthen them—or directly, in which case (*tendo Achillis*, tendons of the *quadriceps*, *pectoralis major*, *deltoideus*, *latissimus*, *ilio-psoas*, *glutei*, etc.), the tendinous bundles meet, under an acute or oblique angle, the surfaces of the bones, and become accurately attached to all their elevations and depressions, without the intervention of periosteum, which is wanting in such places. In the neighbourhood of the bones the tendons frequently contain, for a certain extent, beautiful cartilage cells, which are either isolated or disposed in rows. In exceptional cases, I have also seen the tendinous fibrillæ, at their extremities next the bone, completely incrusted (ossified) with salts of lime in the form of granules. In fibrous membranes, the tendons disappear quite imperceptibly, without any interruption of continuity (*tensor fasciæ*, *biceps brachii*).

§ 82. *Accessory Organs of the Muscles and Tendons.* A. *The muscular Envelopes or Fasciæ.*—These are fibrous membranes which invest single muscles or groups of muscles with their tendons, and have generally the structure of tendons and aponeuroses, especially where they are connected with muscular fibres and tendons; frequently, however, they contain, in their connective tissue, a larger number of fine elastic fibres, or even a very close network of larger elastic elements. The latter structure occurs wherever the fasciæ are destined to form a firm enveloping membrane for the muscles without impeding them in their various changes of form, particularly, therefore, in the middle of the limbs.

B. *Ligaments of the Tendons.*—Besides certain ligamentous parts of the fasciæ, which, being attached to bones, surround the tendons or otherwise confine them, there are the so-called *tendinous sheaths (ligg. vaginalia tendinum)*, as, for example, those of the tendons of the flexors of the fingers and toes, where they consist of numerous small bands arranged in succession, and strengthening the synovial sheaths. Other ligaments comprehended in this section are the *lig. carpi proprium*, the *trochlea*, and the *retinacula tendinum.*

C. *Synovial Bursæ and Synovial Sheaths.*—Wherever muscles or tendons, in performance of their movements, rub against hard structures (bones, cartilages) or against other muscles, tendons and ligaments, there are found between the parts concerned spaces filled with a small quantity of viscid fluid, which, according to *Virchow*, is not mucus, but a substance very similar to colloid matter. These spaces are usually regarded by anatomists as being lined by a special membrane, the *synovial membrane.* But, in point of fact, only the smaller number of these spaces are covered throughout by a continuous membrane, the majority being destitute of it in many places. With regard to the synovial bursæ, those of the muscles (*psoas, iliacus, deltoideus,* etc.) approach most to the condition of continuous sacs; whereas those of the tendons exhibit only an incomplete membrane, and are destitute of it precisely on those parts which glide upon each other. The same observation applies to the synovial sheaths, among which only the common sheaths of the flexors of the fingers and toes present, in a certain measure, the form of a so-called serous sac, although, even here, there are many parts of the tendinous surface devoid of all membranous investment. In most of the synovial sheaths, and in many synovial bursæ, there are occasionally reddish, fringed processes, which, in form and structure, entirely resemble those in the joints, and are nothing but *vascular processes* of the synovial membrane.

D. *Fibro-cartilages and Sesamoid Bones.*—The tendons of some muscles (*tibialis posticus, peronæus longus*) contain, where they run in tendinous sheaths, dense, semi-cartilaginous masses imbedded in their substance, which are known under the name of *sesamoid cartilages*, and of *sesamoid bones* when they become ossified, as occasionally happens. The latter occur normally imbedded in the flexor tendons of certain fingers and toes, with one surface directed towards an articulating cavity.

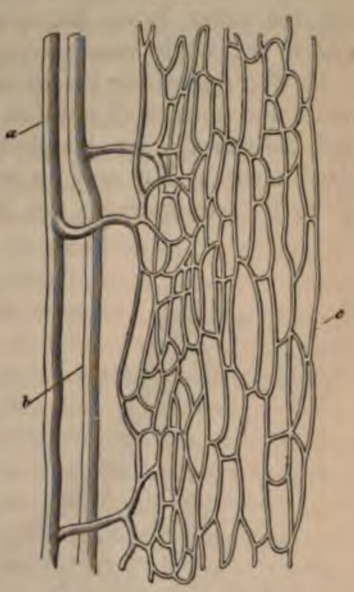
Respecting the intimate structure of the last-mentioned parts, it may be remarked, that the sesamoid bones consist of ordinary fine cancellated osseous tissue, enclosed on one side in tendinous or ligamentous substance, and on the other, projecting into an articular cavity, where the surface is covered by a thin layer of cartilage. The ligaments of the tendons have the same structure as the tendons themselves, with the exception of the more delicately constructed *rectinacula tendinum*.

The *synovial bursæ*, which are invariably thin walled, consist, in as far as they possess a special membrane, of variously decussating, and often anastomosing, loosely connected bundles of connective tissue, together with fine elastic fibres; whilst the synovial sheaths—in conformity with their double office of synovial bursæ at one place, and at another of ligaments of tendons, connected with tendinous sheaths—in their thinner places have the structure of the *bursæ mucosæ*, in their thicker, are composed of dense connective tissue. Both kinds of sacs, together with the parts lying in, or otherwise bounding them, are only partially covered by epithelium, which generally consists of a simple layer of nucleated polygonal cells of 0·004''' to 0·007'''.

The *places destitute of an epithelium*, which may be distinguished by their dull lustre and yellowish appearance, and are especially to be found in localities where the tendons and the parts surrounding them are exposed to a *greater pressure*, invariably exhibit, almost in their whole extent, the nature of fibro-cartilages; the dense connective tissue of which they are made up, and which is mixed with but few elastic fibres, containing cartilage-cells, often in very considerable number, whose size and other characters present almost the same variations as those of the true cartilages. Where the cartilage-cells are deposited in very large proportion, the tendons are thickened, or even, as it were, filled with distinct fibro-cartilaginous masses (*cartilagines sesamoideæ*). Upon the cuboid bone, at the part where the tendon of the *peronæus longus* turns round it, there is a layer of genuine cartilage of $\frac{1}{3}'''$ to $\frac{1}{2}'''$ thick.

§ 83. *Vessels of the Muscles and Accessory Organs.* A. *Blood-vessels.*—There is little peculiar in the ramification of the larger vessels. The trunks passing into the muscles either obliquely or transversely, and, running in the *perimysium internum,* divide, at acute or obtuse angles, in an arborescent manner, so that all parts of the muscles are supplied by them. The finest arteries and veins usually run parallel to the muscular fibres, and form a capillary network between them, which is so characteristic, that when it has been once seen, it can never be mistaken for anything else. The meshes are rectangular, with long sides which run parallel with the longitudinal axis of the muscle; so that the plexus consists of two kinds of vessels; longitudinal, which lie in the furrows between each pair of muscular fibres, or in the irregular spaces between several, as can be especially well seen in transverse sections of injected muscles, and transverse vessels, which, anastomosing in various ways with the former, form a network around the muscular fibres. Thus every individual fibre might in a manner be said to lie in a plexus of capillaries, and is richly supplied with blood on all sides. The capillaries of the muscles belong to the finest in the human body, and have often a smaller diameter than the human blood-corpuscles. In one of *Hyrtl's* preparations, they are 0·0025''' to 0·003'''; in the *pectoralis major*—filled with blood, 0·002''' to 0·003'''—empty, 0·0016''' to 0·002'''.

Fig. 69.



Capillary vessels of muscles, magnified 250 times. *a.* Artery. *b.* Vein. *c.* Capillary network.

The *tendons* belong to those parts of the body which are most sparingly supplied with blood-vessels. The smaller tendons present, in their interior, *not a trace* of blood-vessels, but are supplied abundantly with wide-meshed networks of capillaries in the loose connective tissue surrounding them. In thicker tendons, small solitary vessels are also found in the superficial layers; and in the thickest tendons, sparing vascular networks can be demonstrated by the microscope and injections also in the deeper layers; still even here, the deepest layers are completely destitute of vessels. The above arrangement obtains also in the *ligaments of the tendons*, except that still fewer vessels can be demonstrated in them. The thinner fasciæ are altogether devoid of vessels; the thicker, as the fascia lata, apart from the very vascular loose areolar tissue covering their surfaces, contain a few ramifications. On the other hand, the synovial membranes of the muscular system are rich in vessels, especially their vascular processes.

B. The *Lymphatic Vessels* of the muscles are but few in number; and I find, 1, in small muscles, as, for example, in the *omo-hyoideus* and *subcruralis*, no lymphatic vessels; and, 2, in the largest sized muscles, but only in some of them, lymphatic vessels of $\frac{1}{4}'''$ to $\frac{1}{3}'''$ accompanying the blood-vessels. Now, since the deep or muscular blood-vessels of the extremities are accompanied with but few lymphatic vessels, which certainly do not all come from the muscles, it appears quite justifiable to assume, that the few lymphatics which really occur in the larger muscles, do not penetrate between the secondary fasciculi, but are confined to the more vascular perimysium between the larger and more loosely connected divisions, particularly where it is intermingled with fat, and, therefore, soft; as in the *glutæus*, and in the superficial layers of many other muscles.

Fig. 70.

Terminal expansion of the nerves from a human *omo-hyoideus*, magnified 350 times, and treated with caustic soda. *a*. Meshes of the terminal plexus. *b*. Terminal loops. *c*. Muscular fasciculi.

No one has yet seen lymphatics in the tendons, fasciæ and synovial membranes of the muscular system.

§ 84. *Nerves of Muscles.*—The distribution of the muscular nerves, even as regards their larger sub-divisions, presents many peculiarities. Thus it can be shown in most muscles, that *the nerves come in contact with their fibres only at some few limited points, and are never connected with them throughout their entire length.* With reference to the ultimate termination of the nerves, we find, in all muscles, anastomoses of the finer branches, the so-called *plexuses*. The anastomoses between the larger branches are above all to be seen where the entire nervous ramification lies in a very small space; elsewhere they rarely occur, or are wholly absent. On the other hand, those between the finer and finest twigs (terminal plexus, *Valentin*) are everywhere very numerous, and are chiefly parallel to the longitudinal direction of the bundles, in form of elongated rounded meshes. These terminal plexuses, which have sometimes narrower, sometimes wider meshes, and are formed principally by the ramuscules of one small branch, without, however, being altogether isolated the one from the other, proceed to form what *Valentin* calls *terminal loops*; by which term I understand nothing more than anastomoses of the branches of the last order, effected by a few primitive fibres, or a single one, passing from one twig into the other; in which it is a matter of indifference whether they run in a straight line, or are curved in the form of loops (fig. 70).

Fig. 71.

Divisions of a primitive nerve-fibre, from a facial muscle of a rabbit, with three apparent twigs running out into points. Magnified 350 times.

From the observations of *R. Wagner*, *Luschka* and myself, it is now unquestionable that *free terminations* of the nerve-fibres, similar to those known in the muscles of the lower animals, also occur in the human muscles; and, seeing the results of researches now making in all directions on the terminations of nerves, it may be considered highly probable that the above-mentioned terminal loops are not the ultimate divisions of the primitive fibres, but rather that the fibres which form them, always *terminate* in some other place *with free extremities*, either directly or after previously dividing, as was observed by *Wagner* and me in the muscles of man and mammalia. The trunks entering the muscles consist chiefly of thick nerve-tubes, so that in 100 there are on an average about 12 fine ones. In the interior of the muscles they *become more* slender, so that the terminal plexuses consist only of very fine fibres. These, however, are still dark-bordered, and of 0·001‴ to 0·0025‴ in diameter; and, in particular instances, the successive attenuation of individual fibres can be directly observed, which proves that, at least in these cases, it is not occasioned by division.

Nervi Vasorum occur in all muscles, and, accompanying the vascular bundles according to the size of the latter, form coarser or finer branches. They contain only the finest nerve-fibres, and always follow vessels of sufficient size to be recognised as arteries and veins. I have never seen their termination, and only know this much, that they are often wanting on the smallest veins and arteries, and never occur on the capillaries. Here and there one or more fibres of the muscular nerves are seen joining them, which is in accordance with the fact that the *nervi vasorum* of many parts (the limbs, for instance) may be shown to come from the spinal nerves. The smaller tendons have no nerves; the larger, as the *tendo Achillis* and tendon of the quadriceps, *the centrum tendineum* (*Luschka*) for the most part contain only *nervi vasorum*. *Fasciæ and tendinous sheaths* are destitute of nerves, and also, so far as I have hitherto seen, the *synovial capsules* of the muscular system.

According to my investigations, the distribution of the nerves in many of the small-sized muscles in man, is very limited, so that whilst one part of the muscle is, in its entire breath and thickness, unusually rich in nerves, the rest is entirely, or almost entirely, destitute of them. In other muscles, the nerves are distributed over larger portions, but appear also here to come in contact with each primitive fibre only at one very limited spot. From this we may, with great probability of its truth, deduce the general law, that the muscular fibres do not stand in connection with the nerves in their entire length, but only at one small point; whence the further deduction follows, that when we wish to electrify the muscles and cause them to contract with energy (*électrisation localisée* of *Duchenne*), that point is to be chosen at which the nervous trunk enters it. Long muscles, as the latissimus, sartorius, etc., may, perhaps, form an exception to this law, as in these, perhaps, the fibres come in contact with the nerves at two or three points; but more accurate information is wanting as to the arrangement in these cases.

In many animals belonging to the invertebrata, free terminations of the nervous fibres, and their attachment to the muscular fibres by expanded extremities, are well known. In the vertebrata, *Müller* and *Brücke* first described divisions of the nerve-fibres in the ocular muscles of the pike. In the amphibia, divisions and free terminations have become well known, since *Wagner* discovered them in the frog. The divisions are remarkably beautiful and numerous. They commence, in the small trunks and branches, in nerve-tubes 0·004‴ to 0·006‴ in diameter, and continue to divide, with gradual attenuation of the fibres, till at length very small fibrils of 0·001‴ to 0·0015‴ in diameter result. The divisions are for the most part dichotomous or trichotomous, more rarely multiple; yet *Wagner* once saw eight branches. The terminal fibrils are pale, and simply contoured. They never penetrate into the muscular fibres, but, after a short course, either lie obliquely or transversely upon them, or continue for a considerable distance parallel to them, in order, in both cases, to run out into a point, which is often as fine as a fibril of connective tissue. All these relations may be well seen in the mylo-hyoideus (*Wagner*), and above all in a fine cutaneous muscle of the thorax (*Ecker*), the distribution of the nerves in which has recently been very minutely described by *Reichert*. *Reichert* found here, as in man, that only a small part of the muscle is abundantly provided with nerves; whilst they are few in number in the remaining parts. The nervous trunk supplying this muscle, which consists of 160 to 180 muscular fibres, has, according to *Reichert*, 7 to 10 tubules, and finally forms, by repeated division, 290 to 340 terminations, so that there is more than one termination for every muscular fibre.

§ 85. *Chemical and Physical Relations of the Muscles.*—According to *Bibra*, there are in 100 parts of fresh beef, 72·56 to 74·45 parts of water. The solid parts (25·55 to 27·44), in a man 59 years of age, consisted of a residue insoluble in boiling water, alcohol and ether, 16·83; soluble albumen and colouring matter, 1·75; substance yielding gelatine, 1·92; extractive matter and salts, 2·80: fat, 4·24. The fat is chiefly derived from the blood, the fat-cells in the muscles and the nerves; in part also from the muscular fibres themselves. The substance yielding gelatine comes from the perimysium, a small part also from the vessels and the neurilemma; but not from the sarcolemma, which is still to be seen in thoroughly boiled muscles. The inorganic salts and the albumen come chiefly, perhaps, from the muscular fibres themselves, whence also pre-eminently are derived the salts of lactic, acetic, butyric and formic acids, found in the juice of muscles by *Liebig* and *Scherer*, the free lactic acid, kreatin and kreatinin, the sugar of muscles, or *inosit* and the colouring matter; which substances, including the last mentioned, have their seat, partly in the fibrils themselves, partly, as is especially the case with the albumen, in the intermediate connecting substance. The insoluble residue (16·83) is for the most part due to the muscular fibrils themselves, which, as we have seen above (§ 29), are composed of a substance allied to fibrine. The sarcolemma offers greater resistance to alkalies and acids than the fibrils, and is more nearly related to the *membranæ propriæ* of glands, the walls of capillaries, and the cell-membranes of many cells. The colouring matter of the muscles (and these themselves), like that of the blood, becomes bright red on exposure to the air, and still more in oxygen. It is readily extracted by water, but not by salts, and this fact, viz., the effect of altered concentration of the liquid with which the muscles are saturated, may seem to explain the readiness with which muscles change colour in disease.

The muscles, although softer and more easily torn than the tendons, have, nevertheless, a considerable degree of tenacity, especially during life, and a certain degree of *elasticity*. During life, as *E. Weber* justly observes, they are, even when not acted on by the nerves, for the most part not in their natural form, but in a state of tension, and exert an elastic force, like stretched cords. This is most convincingly demonstrated by the experiment of bringing the limb of an animal into a state of extreme flexion, and after section of the nerves dividing the tendons of the extensor muscles, on which they retract to a considerable degree. This tension of the muscles is very various, according to the position of the limbs. It is slight when the body reposes with the limbs in a semi-flexed position; less or=0 when a muscle rests after it has powerfully acted upon a limb; greater and greatest when its antagonists exert their utmost possible action. According to *E. Weber*, the living but inactive muscles may be compared to caoutchouc, in as much as like that substance they possess a high degree of elastic extensibility, or in other words, a *weak* but very *perfect* elasticity, as may be easily observed in the muscles even of dead animals, when they are alternately stretched and allowed to retract. The elasticity of the muscles being so small in amount, they oppose no obstacle to the motion of the limb; and because it is so perfect, they shrink again to their previous form and length after the greatest extension. This is also shown when the abdominal muscles have been extended in pregnancy and in pathological conditions. When the muscles are in action, their condition as to elasticity becomes altered in a very remarkable manner; 1, the muscles, during their contraction, become more extensible or less elastic; on which account they exert a much less force in contracting, than would be the case if their elasticity remained the same as when in a state of inaction; 2, the condition of elasticity during muscular action, is very various in one and the same muscle; it becomes progressively less during the continuance of action, which is the cause of the apparent exhaustion and loss of power which result. In dead muscles, according to *E. Weber*, the elasticity is not so *perfect*, *i.e.*, the dead muscle does not entirely reassume its former condition after being stretched, and, consequently, also tears more readily, although the *gracilis* muscle can still support a weight of eighty pounds without tearing. At the same time, the muscle is less extensible, more rigid, and less flexible; or its elasticity is *greater*. The phenomena of fatigue in the muscles are accordingly to be distinguished from those occasioned by death. In the former, the diminution of the elasticity takes place under the influence of the nerves and during the contraction of the muscle itself, probably in consequence of the altered molecular nutrition of the muscle, and is, consequently, a vital phenomenon. In the latter, these influences have ceased, and the increase of the elasticity, which occasions the well-known *rigor mortis*, is simply a physical phenomenon, and is not to be confounded with increased *tension* of the muscles, which, under vital influences, takes place during their contraction contemporaneously with diminution of their elasticity.

The tendons are very strong, and but little elastic. They contain, according to *Chevreul*, only 62·03 of water in 100 parts, considerably less, therefore, than the muscles; and consist principally of a substance yielding gelatine; yet they are much less easily resolved into gelatine than other parts.

In my opinion, the muscles are sometimes in a state of tension, sometimes in their natural form, sometimes even, compressed, and the vital contraction may be superadded in all of these three conditions. If a stretched muscle so contracts that it does not assume its natural form, it will, upon remission of the contraction, still be in a state of tension, and retract on being cut through. If, on the other hand, a muscle contract when in its natural form, it will become extended when the nervous influence ceases; as, for instance, the contracted heart, or an isolated muscle stimulated by galvanism. Accordingly, when we speak of the elasticity of muscles, not only their tension, when they are extended, but also that in the compressed condition must be taken into account, which latter appears to me of great physiological importance, in as much as the extension of contracted muscles, as in the case of the heart, or of muscles whose antagonists are paralysed, then becomes intelligible. I do not admit the existence of the so-called *tonus* of the muscles, if by that term is understood a long continuing contraction, maintained without the influence of the will, although originally excited thereby; and I am of opinion, that what has been designated under this name, is, for the most part, only the elastic tension, which has been confounded with the antecedent contraction which it succeeds (see my *Mikr. Anat.* II. i.). With reference to the *rigor mortis*, two important facts have been quite recently brought to light, viz., that it may be annulled by the injection of blood (*Brown-Séquard*), and may take place in the living animal, when the supply of blood is cut off from a group of muscles (*Stannius*). In the latter case, the excitability of the nerves also disappears, and the normal conditions of the muscles and nerves return on re-establishment of the circulation. According to my observation on certain poisons, the *rigor mortis* is quite independent of the nerves of the muscles, and is owing to a peculiar alteration of the molecules of the muscles, which may be produced by different causes (VIRCH., *Archiv.*, 1856).

§ 86. *Development of Muscles and Tendons.*—In man, the muscles first become distinct at the end of the second month of intra-uterine life, but are then recognisable only with the aid of the microscope; and being soft, pale, and gelatinous, cannot be distinguished from their tendons. In the tenth or eleventh week, they can be recognised more distinctly, particularly in specimens preserved in alcohol; and the tendons also make their appearance as somewhat lighter, but likewise transparent streaks. In the fourth month, the muscles and tendons are still more distinct; the former, on the trunk, being slightly reddish; the latter, greyish, and less transparent, but both still soft. From this period onwards, both structures more and more assume the condition which they are afterwards destined to have; so that, in the mature fœtus, they present no difference worthy of note, except that the muscles are softer and paler, and the tendons are vascular, and not so white. With regard to their intimate conditions, the fibres in the embryo, at the end of the second month, are elongated bands (fig. 72), from 0·001‴ to 0·002‴ broad, with nodular enlargements at different points, in which places they are provided with elongated nuclei. These bands appear either homogeneous, or finely-granulated, and only seldom present a very slight indication of transverse striation. These muscular fibres, according to my observation, arise each from a single cell, which increases considerably in length. In the further progress of development, they become broader and longer, and their contents — the original cell-contents — are transformed into the muscular fibrils. In the fourth month (fig. 73), the majority measure 0·0028‴ to 0·005‴ in diameter, some even 0·006‴; whilst others do not exceed 0·0016‴ to 0·002‴. The larger fibres are still flattened, but uniformly broad, and considerably thicker than before, and, for the most part, with distinct longitudinal and transverse striæ; or they even contain fibrils, capable of being isolated. Even in longitudinal, but still better in transverse sections, it may be seen that

Fig. 72.

Muscular fibres of a human embryo of the 8th to 9th week, 350 times magnified; without transverse striæ; a. nuclei.

in many fibres the fibrils do not occupy the whole thickness, but are deposited peripherally, in form of a tube; whilst, in the interior of the fibre, there still exists a homogeneous substance as formerly, which now appears as *a canal inclosed by the fibrils.* All the fibres possess a sarcolemma (*b*), which, on the addition of acetic acid, and caustic soda, can be demonstrated as a very delicate membrane, and may occasionally be raised from the fibrils by the imbibition of water. Moreover, as at first, they present nuclei, which are situated upon the sarcolemma, and frequently raise it into rounded elevations. These nuclei are actively engaged in the process of multiplication; they are all vesicular, rounded or elongated in shape, with very distinct, simple or double nucleoli, of 0·0004''' to 0·0008''' in diameter, and often with two secondary nuclei in their interior. The nuclei are most frequently arranged in pairs, lying close to each other; but, often, also, in groups of three, four, or even six, placed alongside, or following each other. From this period to the time of birth, the muscular fibres do not undergo any notable alteration, except an increase in thickness. In the new-born infant, they measure 0·0056''' to 0·0063''' in diameter, are solid, of rounded-polygonal form, and longitudinally and transversely striped, according to circumstances, as in the adult. Their fibrils may now be very easily isolated, and their nuclei are increased in number.

Fig. 73.

Muscular fibres from a human embryo four months old, magnified 350 times. 1. a fibre with a clear, still-unstriped substance, in its interior; 2. a fibre without such a substance, and with indications of transverse striæ; *a.* nuclei; *b.* sarcolemma.

From the above statement it may be inferred, that the sarcolemma of a fully-formed fibre is nothing but the cell-membrane of a primitive muscular cell, which, by its excessive growth, has given origin to a long fibre, and that the nuclei of the latter are the descendants of the original cell-nucleus, which has multiplied by an endogenous process. The muscular fibrils are the differentiated contents of the original tube, which have become firm. In many cases, it can be demonstrated that they are formed from the sarcolemma inwards; in other instances, perhaps they are developed at once, in the whole width of the tube.

The growth of the entire muscle chiefly depends upon the increase of the length and thickness of the fibres; and the rudiments of all the future fibres appear to be formed as early as the first rudiments of the muscle itself; at any rate, always by the middle of fœtal life. In the embryo of from four to five months, many of them are five times thicker than at two months. In the new-born infant, they measure, for the most part, twice, some even three or four times as much as in the fourth or fifth month; and in the adult, they are almost five times larger than in the new-born infant. With the increase in thickness of the fibres, the fibrils must increase in number, since, according to *Harting*, they are but very little thicker in the adult than in the fœtus (compare *Harting*, *Rech. Micrometr.* and *Hepp*, *l. c.*). In accordance with *Valentin* and *Schwann*, I find that the perimysium is developed after the type of common connective tissue, from the union of fusiform formative-cells.

The elements of the tendons are in no case earlier developed than those of the muscles; as, in embryos, from the eighth to the ninth week, I have never been able to detect a distinct trace of them, whilst the muscular fasciculi appeared very evident. It is not till the third or fourth month, when the tendons become visible to the naked eye, that their elements can be distinctly followed. They then appear as long parallel bands, with elongated nuclei, which bands, as *Schwann's*, and my own observations (§ 26) upon very young mammals, show, take their rise from coalesced fusiform cells. Even in the fourth month, they are distinctly recognisable as primitive bundles, with an undulating course, and bearing at various points elongated nuclei, of 0·0035‴ to 0·006‴ in length, and 0·0016‴ in breadth, but without distinct fibrils, and not exceeding 0·0012‴ to 0·0016‴ in breadth. From this period onwards, to the end of embryonic life, the fasciculi slowly increase in breadth, so that, in the new-born infant, they measure 0·002‴ to 0·0025‴: at the same time their fibrils become developed, and between the fasciculi there appear fine elastic fibres, derived from special fusiform formative-cells. (See above, § 25).

With respect to the *pathological* conditions of muscles, the following remarks occur. The substance of the transversely striped muscles is not regenerated, and when divided by a wound, it heals simply by means of a tendinous cicatrix. A new formation of muscular tissue has been seen by *Rokitansky* in a tumour of the testicle of an individual eighteen years old, and by *Virchow* in an ovarian tumour. In the latter case, which I had an opportunity of observing, the new tissue consisted of long, transversely striped, fusiform cells, each with a nucleus. In hypertrophy of the muscles, which never, or, at least, most rarely, occurs in transversely striped muscles, with the exception of the tongue, heart, and certain respiratory organs (*Bardeleben*), the elements, according to *Hepp* and *Wedl*, appear simply to increase in thickness; and, according to the former, the hypertrophied fasciculi in the heart are four times larger than the normal. A true atrophy takes place in old age. The fibres are then narrow, some only 0·004‴ to 0·008‴ in diameter, friable, and, for the most part, without transverse striæ and with indistinct fibrils. They often contain a large number of yellowish or brown granules and numerous vesicular nuclei with nucleoli, which are often arranged in linear series, or collected in heaps upon the inner side of the sarcolemma; and, singularly enough, exhibit the same indications of an energetic multiplication by endogenous formation, as in the embryo. Besides these, many other pathological processes accompany atrophy of the muscles. In *the formation of fat in the muscles*, which often occurs in the heart, the muscular fibres are gradually displaced by connective tissue and fat-cells developed between them; whilst in their *fatty degeneration*, the fibrils gradually disappear, fat-granules being developed in their place, for the most part in linear series; or even fat-cells are formed within the sarcolemma. At the same time, the muscles become softer, paler, and more yellowish, and the fibres readily break down. Paralysed muscles were found by *Reid* to be thinner, softer and paler, and by *Valentin*, to have indistinct transverse striæ. More recent observers have found in such muscles, for the most part, atrophy with fatty degeneration.

In *emaciated* individuals, the muscles are pale and soft, and the fasciculi small. The muscular fibres sometimes, though rarely, become calcified, so that the muscles split up like asbestos. Ossification of a muscle, as sometimes happens in the deltoid, from pressure of the musket in military exercise (the so-called *Exercirknochen*), arises in the connective tissue, which may also occasion a fibrous metamorphosis of the muscle by its undue increase. In *cancer* of the *pectoralis major*, I found the sarcolemma filled with beautiful rows of pale nucleated cells. Of *parasites*, may be mentioned the *Cysticercus cellulosæ*, which lies between the fasciculi, and *Trichina spiralis*; further, a nematoid worm, which BOWMAN (*Cyclop. of Anat.*, ii., p. 512) saw living in the almost empty sarcolemma of the muscles of the eel. Organic formations — but whether of vegetable or animal nature, is uncertain — are found in rats and mice, as white streaks of 4‴ to 7‴ long, and 0·09‴ to 0·1‴ broad, and, on microscopical investigation, seem to be *hollow primitive fasciculi* filled with elliptical, slightly curved corpuscles, of 0·004‴ to 0·005‴ long, and 0·0019‴ broad, resembling eggs.

§ 87. *Physiological Remarks.*—The most conspicuous property of the muscles is their contractility. In contraction, the fibres shorten themselves rectilinearly, and, at the same time, become thicker, but without any notable increase in density. Probably the contraction, as a rule, takes place contemporaneously in all parts of a fibre, although it is possible that contraction may begin in the parts where the nervous terminations are situated, and precede, though by a space of time immeasurably short, or at least inappreciable to the eye, that of the rest of the fibre. In certain circumstances *successively advancing* and *partial* contractions are also observed. If the longitudinal and transverse striæ be watched during the contraction of muscle, it is not difficult to perceive that the former, should they have been present, disappear, whilst the transverse striæ become more distinct and approach each other. From this it may be concluded, that, in the contraction, the principal phenomenon consists in the fibrils becoming shorter and broader, and that by this means the above-mentioned alterations of the fibres are brought about. Moreover, the appearance of transverse striæ is obviously a physical and not a vital phenomenon, for they are seen in dead muscles; and, consequently, do not depend upon partial contractions of the fibrils. They seem rather to arise from the fibrils not being *homogeneous* throughout, but divided into small segments. At the same time, on the opposite hypothesis, they may be explained by supposing that the fibrils are soft threads which, during these contractions, bend in a zigzag or undulating manner, or acquire varicosities. With regard to the sarcolemma, it is probably non-contractile, and serves merely as an enveloping membrane.

It would not be suitable here to enter at length on the causes which produce muscular contraction. I shall, therefore, confine myself to the following remarks. It is undoubted that the capability of contraction is inherent in the muscular substance, and is only, as it were, called into play by the nerves (see my experiments with Urari poison, Virchow, *Archiv.* x. which speak strongly in favour of the inherent irritability of muscle). On the other hand it is just as certain, that hitherto no perfectly decisive fact has been brought forward to prove that the striated muscles contract without having been acted on by nerves. What may be the processes which take place in the fibrils during the contraction is altogether uncertain; but, it is to be hoped, that by following out the investigation of the laws of the electric currents in the muscles, in the way so successfully pursued by *Du Bois Reymond*, some light may be thrown upon this obscure subject. It would be rash to hazard an opinion on the manner in which the nerves act upon the muscles, since the processes which take place in the nerves are as obscure as those in the muscles themselves. This much may, however, be remarked, that since it is shown that in many animals the motor nerves come into contact with the individual fibres only at a few points, and never penetrate into their interior, the nerves must exert their influence at a certain distance in the contraction of a muscle. An important observation has been made by

Duchenne, that in atrophied muscles no longer obeying the will, the atrophy may be corrected by the employment of galvanism regularly continued, so that, finally, such muscles again become subject to the will. If the statement of *Duchenne* be confirmed, that the same thing may, in some measure, be effected in muscles which have ceased to contract when stimulated by galvanism, it seems difficult to avoid the conclusion, that in these cases the galvanism acts directly on the muscular fibres, and, by in some way affecting their nutrition, renders them capable of again performing their functions.

The muscles also possess *sensibility*, but of a peculiar kind, inasmuch as punctures, burns, and cuts of their substance do not occasion notable pain; whilst, on the other hand, all muscles are painful after long-continued action, or when affected with cramp, and become very sensitive to pressure. They also possess a very fine sensation of their own condition of contraction, and very slight variations in the force exerted by them may be discriminated. This apparent contradiction is explained by the fact, that the muscular nerves contain but few sensitive fibres, as may be easily demonstrated in the nerves of the ocular muscles for instance. These fibres, to which those above-described as scantily distributed over the whole muscle probably belong, are too sparing in numbers to make a muscle sensitive to local influences, but suffice, when they are implicated by the contraction of the whole muscular mass, to convey to the sensorium a notion of the degree of pressure which they suffer, and, in over-exerted muscles, to occasion pain, in consequence of the oft-repeated irritation, or of the compression they undergo from rigidity of the muscles.

In investigating the muscles, it is necessary to study them in the fresh condition, and also when treated with various re-agents. *Muscular fibres* are most readily isolated in muscles which have been boiled, or preserved in alcohol, on which, also, the transverse striæ are very beautiful; likewise after treatment with corrosive sublimate or chromic acid. For the study of the transverse striæ, it is, moreover, indispensable to examine muscles in various conditions of extension and contraction. The observation of the first point is highly instructive, and may be easily carried out by examining a thin, slender muscle, such as the hyo-glossus of a frog in different degrees of tension, upon an object-plate of wood, with an opening in the middle filled up with glass. With this arrangement, it may be seen that when the muscle is in no degree stretched, the transverse striæ are fine (0·0004‴) and very close to each other, and the fibres broad. Under full extension, on the other hand, the striæ are 0·0008‴ broad and the same distance from each other, and the fibres narrower. The *contractions* are to be examined in fresh, still quivering muscles, moistened with serum, albumen, or vitreous humour; or by *Ed. Weber's* method, which consists in galvanising, by means of the rotation-apparatus, the muscle to be examined, such as the abdominal muscles and thin muscles of the extremities of the frog, cutaneous muscles, the diaphragm of small mammalia, etc. For this purpose, the muscle must be placed upon a slip of looking-glass, from the middle of which the metallic coating has been removed for a small extent; and while one electrode is kept in connexion with the metallic surface at one end of the muscle, the other electrode is applied to the metallic covering at the other end, and the effect watched with the microscope.

Fig. 72.

A muscular fibre of a frog, in different degrees of extension. A. Stretched out and thin, with broad distant striæ. B. The same not extended, thicker, and with narrower, closely approximated striæ. Magnified 350 times.

The sarcolemma can be readily demonstrated in the muscles of amphibia and fish, particularly in those preserved in spirit, in which it is separated from the fibrils at various points. In the higher animals, it is occasionally seen on teasing out the fibres; further, in fibres which have been macerated or boiled, and also on the addition of acetic acid and alkalies. I can especially recommend caustic soda for this purpose, which, in many cases, renders the contents of the muscular tubes so fluid, that they flow out, together with the nuclei, in a continuous stream, and then the sheaths come very distinctly into view. But the sheaths are nowhere more beautifully seen in human muscles than in such as are softened, atrophied, affected with fatty or other species of degeneration; and the more so, indeed, the more advanced and decided is the degeneration of the fibrils.

In fresh muscles, the muscular fibrils may always be seen in transverse sections (amphibia), and in the thoracic muscles of insects; most beautifully in beetles (*Aubert*). They may also be seen elsewhere, but only now and then, and in favourable circumstances. They are readily isolated in preparations preserved in alcohol, especially in the perennibranchiata (siredon, proteus, etc.), by treatment with chromic acid (*Hannover*), by maceration for from eight to twenty-one days at a temperature of 1° to 8° R. in water, to which some corrosive sublimate has been added, to prevent putrefaction (*Schwann*); maceration, also, in saliva (*Henle*) allows of their being readily demonstrated; whilst, according to *Frerichs*, in the stomach, the fasciculi break up into Bowman's discs, or at least break in the transverse direction; and this, according to *Lehmann*, also takes place by maceration in concentrated nitric and hydrochloric acids, in nitrate of the protoxide of mercury (which, after it has acted for a time, colours the contents of the fibres red, but not the sarcolemma), and in carbonate of potash. The nuclei of the muscular fibres can be best studied on the addition of acetic acid; they may be isolated by caustic soda (see above), and they swell up under the operation of potash (*Donders*). Respecting the action of various re-agents upon the muscular elements, the treatises of DONDERS (*Holländ. Beiträge*), PAULSEN (*Observ. Microchem*, Dorp., 1849), and LEHMANN (*Phys. Chem.*, Bd. iii.), may be consulted. The vessels of the muscles are studied in thin, fresh muscles, and in injected preparations; the nerves may be seen in the smallest human muscles, in the muscles of small mammalia, in the cutaneous muscle on the thorax of the frog, with and without the addition of caustic soda. The perimysium, and the form and position of the muscular fibres, are very beautifully exhibited in transverse sections of half dried muscles. The same remark applies to the elementary tissues of the tendons. The attachments of the latter to the bones and their cartilage-cells in such places — in the *tendo Achillis*, for example — are readily seen in perpendicular sections of dried preparations. Respecting their relation to the muscular fasciculi, see § 81. For the investigation of the cartilage-cells in the tendons, horizontal sections are made at the surface, and treated with acetic acid or very diluted caustic soda. For the study of the development of muscle, the naked amphibia are, above all, to be recommended, the mammalia being not so well adapted for the purpose.

Literature.—In addition to the treatises cited in § 30, the following may be consulted. H. R. Ficinus, *de Fibræ muscularis Forma et Structura Diss., inaug. Lipsiæ*, 1836, 4, *cum tab.* Ed. Weber, in R. Wagner's *Handwörterb. der Phys.*, Bd. iii., 2 Abth., 1846. Dobie, in *Ann. of Nat. Hist.*, 2 Ser. iii., 1849. Lebert, in *Ann. d. Sc. N.*, 1850, p. 205. Aubert, in *Zeitschr. f. Wiss. Zool.*, iv. p. 388. Stannius, in *Gött. Nachr.*, 1852, No. 17; and *Zeitschr. f. Wiss. Zool.*, iv., fig. 252. Donders, in *Ned. Lancet*, 3 Ser. i., Jahrg., p. 556. Gairdner and Barlow, in *Monthly Journal*, 1853, pp. 278, 872. Ecker, *Icon. Phys.*, Tab. xii. Funke, *Atlas der Phys. Chem.*, Tab. x. Kölliker, *Zeitschr. f. Wiss. Zool.*, Bd. viii. ix. Savory, in *Phil. Transact.*, 1856. A. Rollet, in *Proc. of the Acad. of Vienna*, 1856.

Of the Osseous System.

§ 88. The osseous system consists of a numerous collection of hard organs, *the bones (ossa)* having a peculiar, uniform structure, which, either directly, or by means of other parts, as *cartilages, ligaments*, or *articular capsules*, are united to form a connected whole — the *osseous framework*, or *skeleton*.

In man, the osseous tissue exists in two forms, *compact* and *spongy*. The former is solid only in appearance; for even with the naked eye, fine canals may be seen penetrating it in various directions, and many still finer are discovered by microscopical examination. These *vascular* or *Haversian canals* ('medullary canals' of authors) may be said to be almost wholly absent in the spongy substance, being there represented by wider, rounded, or elongated spaces filled with marrow (in some bones with veins and nerves [*cochlea*]). These are called *medullary spaces*, or medullary cells *(cancelli, cellulæ medullares)*, and are visible without the aid of magnifying powers. They all communicate with each other, and are surrounded by a small quantity of osseous tissue, which, assuming the form of fibres, laminæ, and trabeculæ, is so disposed as to constitute a pretty regular network. If the spaces are larger, the substance is called *substantia cellularis*; if they are smaller, *substantia reticularis*. The latter, in some places, where its spaces become narrower, and the osseous trabeculæ thicker, approximates in structure to the compact osseous substance, without, however, being really converted into it, and, in other places, passes, without any sharp line of demarcation, into compact tissue. This, however, does not prove that both are identical, but, as shown by their development, simply depends upon the circumstance, that the spongy substance frequently arises from the opening up of the compact by partial absorption. The above-mentioned two substances are very variously concerned in the formation of the bones and different parts of bones. The compact substance is found alone and without vascular canals, only in a few places, as in the *lamina papyracea* of the ethmoid bone, some parts of the lacrymal and palate bones, etc.; but more frequently with vascular canals, as in the thinnest parts of the scapula, ilium, acetabulum, and flat cranial bones (*ala magna, parva, processus orbitalis ossis frontis*) in many individuals. Spongy tissue, with a thin compact cortex without vascular canals, exists in the ossicles of the ear, on all the surfaces of bones which are covered with cartilage, and perhaps, also, in small spongy bones. In all other, and, therefore, the most numerous cases, the two substances occur together, but in a such a manner, that sometimes the spongy substance preponderates (spongy bones and parts of bones), as in the *vertebræ*, *carpus* and *tarsus*, sometimes the

Fig. 75.

Segment of a transverse section, from the diaphysis or shaft of the femur of an individual eighteen years old; magnified 25 times. *a*, Haversian canals; *b*, opening of the same inwards; *c*, outwards; *d*, osseous substance with lacunæ. No transverse sections of vascular canals or principal lamellæ are seen.

compact, as in the diaphyses of the long bones; or both are present in about the same proportion, as in the flat bones.

§ 89. *Intimate Structure of the Osseous Tissue.*—The osseous tissue consists of a dense, for the most part indistinctly stratified *basal substance* or *matrix*, penetrated by vascular canals, and of many small microscopic spaces, the *bone-cavities*, *lacunæ* (bone-corpuscles of authors), furnished with fine hollow processes, the *canaliculi*.

The *vascular canals of the bones*, or *the Haversian canals* (medullary canals of authors), are fine tubes, of an average breadth of 0·01‴ to 0·05‴, but varying from 0·004‴ to 0·18‴, which, except in the above-mentioned localities, are everywhere found in the compact osseous substance, and form in it a network with wide meshes, similar to that of the capillary vessels. In the cylindrical bones, as also in the ribs, the clavicle, pubes, ischium, and inferior maxilla, they run chiefly in a direction parallel to the long axis of the bone; and, in longitudinal sections, whether parallel to the surface or perpendicular to it, appear at distances of 0·06‴ to 0·14‴ apart. They are connected with each other by small branches running obliquely or transversely, as well in the direction of the radius as that of the tangent of the transverse section. Accordingly, in a longitudinal section parallel to the surface, or perpendicular to it, there are seen, with a low magnifying power, canals lying closely together, and principally longitudinal and parallel to each other. Here and there, they are united by connecting branches, so that elongated, and, for the most part, rectangular meshes are formed, which, in the young osseous substance, are disposed much more closely than in the fully developed layers. A transverse section shows chiefly transverse sections of the canals at tolerably regular distances from each other (fig. 76), and occasionally, especially in young bones, connecting branches in a tangential direction, and some anastomoses radially. Fœtal and unfinished bones present, in cross sections, almost no transversely cut canals (fig. 75), but chiefly such as run horizontally in the direction of the tangent and radius, so that the bones appear to be wholly composed of short thick layers, each of which, on close examination, is found to belong to two canals, which relation is also indicated by a faint line of separation in the middle of each layer. In man, this condition is still observable in the eighteenth year.

In the *flat bones*, only a few of the canals run in the direction of the thickness of the bone, their general course being parallel to its surface, and mostly in lines which may be conceived to radiate from a point (*tuber parietale, frontale*, upper anterior angle of the *scapula*, articular part of the *ilium*) in a stellate manner towards the borders; more rarely, all parallel to one another, as in the sternum. Lastly, in the *short bones*, one direction also preponderates; thus, in the bodies of the vertebræ the prevailing direction is perpendicular; in the *carpus* and *tarsus*, etc., it corresponds with the long axis of the limb. It is, however, to be observed, that the more considerable processes of these bones (for example, those of the vertebræ) deviate from this condition, and present the same arrangement as the short cylindrical bones, which is the case, indeed, with similar processes of other bones, such as the coracoid, styloid, etc. The laminæ, fibres, and trabeculæ of the *spongy substance*, when rather thick, contain here and there vascular canals. As the Haversian canals contain bloodvessels, they open at certain places, namely, upon the outer surface of the bones, and on the walls of the medullary cavities and spaces in the interior; in all of which places smaller and larger pores are perceived, which are, in part, visible to the naked eye, and are the more numerous the thicker the cortex of the bone. The relation of the vascular canals within the *compact substance* to those which penetrate it from without, or at its inner boundary, can be compared to that between the branches and trunks of vessels only in the outermost and innermost layers of the cortex. In the interior of the cortex, the canals can, morphologically, be most aptly compared with a capillary network, which, at its boundaries, stands in many places in connection with larger canals. Where cortical substance adjoins spongy substance, as within the extremities of the diaphyses and in the lateral circumference of the apophyses, the vascular canals, widening in an infundibuliform manner, sometimes suddenly, sometimes gradually, and anastomosing more frequently, thus pass into medullary spaces of various widths (Haversian spaces, *Tomes* and *De Morgan*), so that there is often no sharp line of demarcation visible between them. I have never yet seen blind terminations of the vascular canals; yet it is certain that, in many places, and also upon the surface, they must form closed networks over a considerable extent, viz., wherever very few or no vessels penetrate into the compact substance, as at the places of attachment of many tendons and ligaments, beneath many muscles, etc. (origin of the temporal muscle from the parietal bone).

§ 90. The *substance* of the bones is stratified, and the *osseous lamellæ* (fig. 76) come still more distinctly to view in bones deprived of their calcareous earths, or in such as have been exposed to the weather or calcined; in which cases the laminæ exfoliate, and in the bone-cartilage can also be raised up with the forceps. In the middle part of the cylindrical bones, they form two systems, a *general*, which runs parallel to the outer and inner surfaces of the bones, and *many special*, surrounding the separate Haversian canals. These systems, it is true, are in many places immediately connected with each other, but, for the most part, are only in apposition, and can, therefore, be conveniently regarded as being of two kinds, which view is also to some degree supported by their mode of development.

Fig. 76.

Segment of a transverse section of a human metacarpal bone, treated with concentrated oil of turpentine; magnified 90 times. *a*. Inner surface of the bone, with the inner fundamental lamellæ; *b*. transverse section of the Haversian canals, with their lamellar systems; *c*. interstitial lamellæ; *d*. lacunæ and their processes.

The lamellæ of the Haversian canals (fig. 76) surround those channels concentrically, in greater or less number. They form, as it were, their walls, and are connected with each in a similar way as the layers of the walls of the larger vessels. In general, the widest canals have the thinnest walls; those of middling size, thicker; and the narrowest, again, less thick walls. The thinnest walls which I have in general seen amounted to 0·008‴ to 0·02‴ in thickness; the thickest, 0·08‴ to 0·1‴. The thickness of the lamellæ varies between 0·002‴ and 0·005‴, and is, on an average, from 0·003‴ to 0·004‴; their number is, as a rule, 8 to 15, but may not exceed 4 or 5, or may amount even to 18 or 22.

The lamellæ of the Haversian canals extend, with the canals to which they pertain, to the inner and outer surface of the diaphyses, and are here connected with the above-mentioned general lamellæ, the *fundamental laminæ*, which form an outer and an inner layer, and which, besides, penetrate into the diaphyses between the special systems of lamellæ round the Haversian medullary canals (interstitial layers). The former two layers, or the *outer and inner fundamental lamellæ*, run parallel to the outer and inner surfaces of the bone, and vary in their thickness from 0·02‴ to 0·3‴, or even to 0·4‴. The latter, or the *interstitial fundamental lamellæ*, where the superficial fundamental lamellæ are developed, are most distinctly seen when they are connected with these, running parallel to them, and penetrating from without and from within into the substance of the diaphyses, so as to be interposed between the other lamellæ in masses of 0·02‴ to 0·12‴ in diameter. In the interior of the compact substance, the Haversian systems of canals in man are usually so close together, that the existence of special collections of lamellæ between them is out of the question; and lamellæ, which in cross sections apparently run parallel to the surface in the situation referred to, will be found almost always to belong to canals running horizontally, for it is but rarely that more distinct intermediate masses also appear here, though this is generally the case in mammalia; moreover, certain interstitial lamellæ may be regarded, with *Tomes* and *De Morgan*, as the remains of Haversian systems partly absorbed. The individual lamellæ of the above-described systems have the same thickness as those of the Haversian canals, and their number varies from 10 to 100.

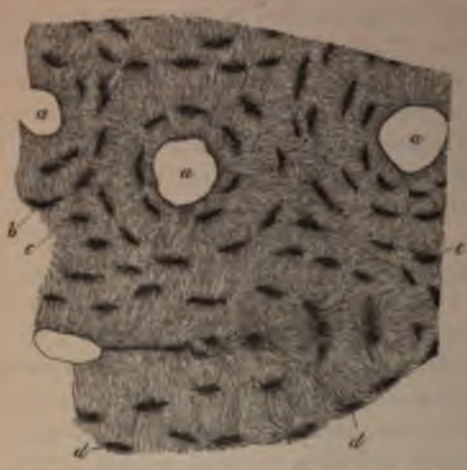
Hitherto, we have spoken only of the diaphyses of long bones. In the *apophyses of the long bones* the thin cortex, as was to be expected, exhibits but few Haversian systems of lamellæ, although these present the same characters as in other parts. The outer fundamental lamellæ are scanty; within, they are wholly wanting, on account of the spongy substance here present. In this, the very scanty Haversian canals present the usual systems of lamellæ, but thin, and the remaining substance, according to the nature of the osseous network, consists of a lamellated and fibrous tissue, which, in general, has the same course as the contours of the medullary spaces and cells. The flat and short bones present, in their interior, the same arrangement, whilst their cortex deviates from that of the long bones only in this, that the fundamental lamellæ in the flat bones run parallel to both the surfaces of these bones. The thickness of the fundamental lamellæ in the cranial bones (parietal bone) is sometimes the same within and without, viz., 0·08‴ to 0·16‴; sometimes they are wholly absent externally in parts where the bone is very vascular, and the Haversian lamellæ extend almost to the surface.

With respect to the *intimate structure* of the osseous lamellæ, a sufficiently thin section of dry bone, polished, and especially a transverse one, usually presents, apart from the lacunæ and canaliculi, an extremely fine but very distinct punctuation in the lamellæ, which are generally not very distinct, so that the whole osseous tissue appears granulated, and as if composed of closely arranged pale granules, of 0·0002‴ in size. If water, or a weak solution of sugar or albumen, be added to a section, two layers, as it were, appear, in many cases, in each lamella, one pale and more homogeneous, the other darker granulated, and generally also striated. In sections parallel to the surface, the bone, in many places, appears almost entirely homogeneous, without any trace of a granular structure; in others, an indistinct granular aspect, or small points *(Deutsch)*, are exhibited, and with a longitudinal striation, which is referred by *Sharpey* to reticularly united fibrils. Frequently there is also exhibited, in the cartilage of the decalcified compact substance, a coarse fibrous appearance, which arises, perhaps, from the fibrous bundles of the former blastema. If bones be calcined and the fragments crushed, small angular granules, according to *Tomes*, come to view. They are, according to *Tomes*, $\frac{1}{3}$rd to $\frac{1}{8}$th of the diameter of human blood-corpuscles; according to *Todd* and *Bowman*, $\frac{1}{6000}''$ to $\frac{1}{14000}''$; and are also obtained by boiling bones in a Papin's digester. From this, and from the granular appearance of fresh bones, to which also *Tomes* and *Todd* and *Bowman* call attention; further, from the nearly equal size of the granules seen here with those demonstrated by *Tomes*; and lastly, from the circumstance that bones, when treated with hydrochloric acid and when calcined, exhibit in both cases a similarly continuous substance without interstitial vacuities, it may be assumed that the osseous tissue, in mammalia and man, consists of an intimate mixture of organic and inorganic compounds, in the form of firmly united fine granules; although we do not by this mean to deny that perfectly homogeneous osseous tissue may be found in the lower animals, and in certain places in the higher (see *Tomes* and *De Morgan*, l.c., pp. 13, 14).

§ 91. *Lacunæ and Canaliculi.*—Scattered through the whole osseous substance and in all the lamellæ, there are seen, in dry sections, microscopic corpuscles of the form of cucumber seeds, with many fine branched and, in part, anastomosing rays. These corpuscles are dark by transmitted, and white by reflected light, which is owing, not to a deposit within them of calcareous salts, as was formerly believed, whence they were called *bone-corpuscles*, or *calcigerous corpuscles*, but simply to their being filled with air. In fresh bones, there exists in every lacuna a delicate-walled cell, completely filling it, with clear contents and a single nucleus. This included cell sends out many fine processes into the canaliculi, and is connected with similar processes of neighbouring cells. I call these cells, in honour of their discoverer, *Virchow's bone-cells*, and will, further on, discuss their great physiological importance.

Although *Virchow's* cells are, properly, of more importance, yet, in the following description, we shall refer more to the bone-cavities accurately surrounding them, because in the bones which are usually the subject of examination the inclosing cavities are almost alone visible. These are oval, flattened spaces of 0·01‴ in medium length, 0·004‴ broad, and 0·003‴ thick, which, both from their borders and surfaces, but especially from the latter, give off a large number of very fine canals, of 0·0005‴ to 0·0008‴ in diameter—the *canaliculi*. The lacunæ are equally numerous in both kinds of the above-described systems of lamellæ, and are situated so closely to each other, that, according to *Harting*, there are from 709 to 1120, or, on an average, 910 in a square millimeter. They generally lie in the lamellæ, but also between them, and are arranged, without exception, with their broad sides parallel to the direction of the lamellæ. The canaliculi which proceed from them take an irregular and often a bending course, branch out in various ways, and penetrate the osseous substance in all directions. For the most part, however, they pass from the two surfaces of the lacunæ straight through and across the lamellæ, and also from the two poles of the lacunæ in a direction parallel to the Haversian canals. It is only in certain places that the *canaliculi terminate in blind extremities*; in all other localities a certain number of them *anastomose* in various ways with the canaliculi of neighbouring lacunæ, whilst another part open into the vascular canals, the medullary cavities and spaces of the spongy substance, or terminate free upon the surface of the bone. There is thus formed a connected system of cavities and canals traversing the whole osseous substance, by

Fig. 77.

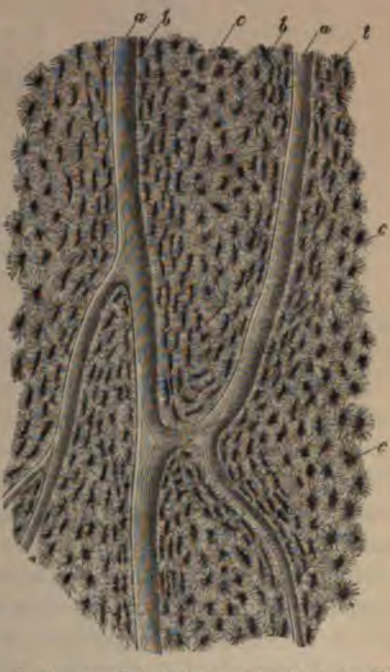


From a transverse section of the diaphysis of the humerus, magnified 350 times. *a.* Haversian canals; *b.* lacunæ with their canaliculi in the lamellæ of the same; *c.* lacunæ of the interstitial lamellæ; *d.* others at the surface of the Haversian systems, with canaliculi going off from one side.

which, in virtue of *Virchow's* cells existing in them, the nutrient fluid secreted from the vessels is conducted even into the densest parts.

The lacunæ and their canaliculi do not present entirely the same relations in all parts of the bones. In the lamellæ round the Haversian canals, the elongated lacunæ, when viewed in transverse sections (fig. 77), are, by reason of their curvature, arranged, as it were, concentrically; and their very numerous canaliculi give rise to a very close striation radiating from the vascular canals. The lacunæ are sometimes extremely numerous, sometimes more sparing; in the former case, they alternate with tolerable regularity, or are disposed in succession in the direction of the radii of the concentric lamellæ; but frequently they are arranged very irregularly, collected in heaps, or separated by larger intervals. In longitudinal sections of Haversian canals (fig. 78), the lacunæ are seen as narrow elongated objects, arranged in linear series and disposed in several layers parallel to the canals. They are likewise provided with numerous canaliculi, which pass, for the most part, directly inwards and outwards (therefore transversely through the lamellæ), and a smaller portion parallel to the long axis of the canals. If the section happens to fall on the surface of a system of lamellæ, the lacunæ are seen flatways, and then appear in the form of beautiful rounded, or oval, or irregularly outlined bodies, with tufts of canaliculi (fig. 79), which are directed towards the observer, and, consequently, appear more or less foreshortened, whilst a small number of others run along the lamellæ. In the thinnest parts of a section, there is seen occasionally a tuft of

Fig. 78.



Section parallel to the surface, from the diaphysis of a human femur; magnified 100 times. *a*. Haversian canals; *b*. lacunæ seen from the side, belonging to the lamellæ of the same; *c*. others seen from the surface, in lamellæ which are cut horizontally.

transversely cut canaliculi, without their appertaining lacunæ, which gives rise to a cribriform appearance (fig. 79, *a*). The innermost lacunæ of a Haversian system send all the canaliculi

Fig. 79.

Section from the parietal bone. Lacunæ with the canaliculi seen from the surface; magnified 450 times. The points upon the cavities, or between them, belong to the cut canaliculi, or are the openings of the latter into the lacunæ. *a a*. Groups of transversely cut canaliculi, each belonging to a lacuna which has been destroyed in the preparation of the section.

arising from their inner surface to the Haversian canal, into which they thus open. From the borders and from the outer surface other canaliculi arise, which, perhaps, occasionally terminate in blind extremities, but chiefly anastomose with those of the neighbouring, and more especially of the outer lacunæ. Thus, whilst all the successive lacunæ are connected with each other, the network of canaliculi and lacunæ extends to the outermost lamella of the system, where the lacunæ are either connected with those of neighbouring Haversian systems or of intermediate lamellæ, or end without further connexion. In the latter case, all, or at least the majority and the longest of their canaliculi, proceed inwards, *i. e.*, towards the vascular canal whence they are supplied with nutrient fluid.

In the *interstitial osseous substance* between the Haversian systems, when it is present in small quantity, the lacunæ, few in number, often not exceeding from 1 to 3, are less regular in arrangement, and have also a more rounded form. If the interstitial substance is distinctly lamellated and in larger quantity, the lacunæ are more regularly disposed, with their surfaces parallel to the lamellæ. The canaliculi of these lacunæ are also connected with each other, and with those of neighbouring systems. Lastly, in the outer and inner *fundamental lamellæ*, all the lacunæ are arranged with their surfaces parallel to the lamellæ, and, accordingly, directed, for the most part, inwards and outwards. In transverse sections, they present the same characters as those of the Haversian systems, but, except in the smallest cylindrical bones, are little or scarcely at all curved. In sections, whether perpendicular or parallel to the surface, they exhibit the same relations as those above described, but with this qualification, that, as might have been expected, a larger number of lacunæ are seen flatways in the same section, and that the above-mentioned cribriform appearance, which gives the bones a great resemblance to certain sections of the teeth, is more frequently observed. The canaliculi of these lamellæ partly anastomose as usual with each other, partly terminate upon the outer and inner surfaces of the bones. Where tendons and ligaments are inserted into bones, the canaliculi of the outermost lacunæ are, perhaps, connected with the adjoining plasm-cells of the fibrous tissue, or end in blind extremities, which last condition is always found in the parts covered with cartilage (articular extremities, ribs, surfaces of the bodies of the vertebræ, etc.). In the trabeculæ, fibres, and laminæ of the *spongy substance*, the lacunæ have all possible directions; but are, for the most part, arranged with their long axes parallel to those of the fibres, trabeculæ, etc., and with their surfaces directed towards the medullary spaces. They also here intercommunicate by means of their canaliculi, which, where they proceed from the outermost lacunæ, open into the medullary spaces.

Within the lacunæ, *Donders* and I found a clear, probably viscid fluid, with a cell-nucleus. If bone-cartilage be boiled in water, or in caustic soda, from one to three minutes, these nuclei come into view very distinctly, or dark corpuscles appear, which are to be regarded as the contracted cell contents, together with the nuclei, and thus analogous to the cartilage-corpuscles. Subsequently, *Virchow* (see *Würzb. Verh.*, No. 13) discovered that the lacunæ and canaliculi can be isolated by macerating bones in hydrochloric acid as stellate cells; a fact which, although confirmed by me and others, was not fully appreciated until the doctrine of the primordial utricle was applied by *Remak* and me to animal cells, and *Virchow* had demonstrated the conversion of plasm-cells into bone-cells. Accordingly, *Virchow's* bone-cells are to be ranked with the primordial utricles of the cells of ossifying cartilage, and the plasm-cells of periosteal deposits; whilst the lacunæ, in the latter case, simply represent gaps in the matrix or basal substance; but in the former, are cavities within the thickened capsules or secondary cell-membranes of the cartilage-cells, which membranes have become ossified and coalesced with the intermediate substance. In the cement of the tooth of the horse, the secondary capsules, as I find, can also be isolated with the bone-cells by maceration in hydrochloric acid.

Tomes and *De Morgan* describe in the circumferential laminæ of bones a peculiar kind of canaliculi, in form of elongated tubes, which pass in bundles or singly, more or less obliquely from the surface towards the interior of the bone. When long, they are sometimes bent once or twice at a sharp angle. They have parietes, and are connected laterally with the canaliculi.

§ 92. *Periosteum.*—This is a slightly glistening, yellowish-white, vascular, extensile membrane, which covers the greater part of the surface of the bones, and from the numerous vessels which it sends into their interior, is of the greatest importance for their nutrition.

The periosteum, which is sometimes thicker, sometimes thinner, presents almost everywhere, excepting only where muscles arise directly from it, two layers, which, although firmly united to each other, can be more or less perfectly distinguished by their structure. The outer layer is formed principally of connective tissue, and occasionally a few fat cells, and is the principal seat of the vessels and nerves belonging to the membrane; whilst in the inner layer, elastic fibres, generally of the finer kinds, form continuous and often very dense net-works—in fact, real elastic membranes superimposed in several layers—the connective tissue forming the less important element. Nerves and vessels also occur in this layer, which, however, only pass through it, being destined for the bone itself.

§ 93. *Marrow.*—The marrow, which is found in all the larger cavities of the bones, with the exception of most of the Haversian canals, and the smaller nervous canals of the flat cranial bones, appears in two forms, namely, *yellow* and *red*. The former is found as a softish mass, especially in the long bones, and consists of 96·0 fat, 1·0 areolar tissue and vessels, and 3·0 of fluid with extractive matters; whilst the latter occurs in many apophyses, in the flat and short bones, but above all in the bodies of the vertebræ, the

Fig. 80.

Two fat cells, from the marrow of the human thigh-bone; magnified 350 times. *a*, Nucleus; *b*, cell-membrane; *c*, contained oil-globule.

base of the cranium, the sternum, etc.; and in addition to its reddish or red colour and slight consistency, is characterised by its chemical properties. According to *Berzelius*, that of the diploë, contains 75·0 water, 25·0 solid substance, namely, albumen, fibrin, extractive matter and salts, and only traces of fat. The yellow medulla consists, apart from vessels and nerves, of areolar tissue and fat-cells; the red, on the other hand, of a small quantity of areolar tissue, numerous, slightly reddish, small cells, which I call medullary cells, and fat-cells with a large quantity of fluid.

§ 94. *Connections of the Bones.* A. *Synarthrosis*, connection without articulation. 1. *By Suture.* In this mode of articulation, the bones are united by a very thin whitish membranous strip of connective tissue, which, as long as the bones continue to grow, is very conspicuous. Afterwards, this *sutural ligament* becomes thinner, and disappears with the obliteration of the sutures. 2. *Connection by ligaments. Syndesmosis* is effected by fibrous and elastic ligaments. The *fibrous ligaments* constitute the majority of ligaments, are white and glistening, and agree in their structure, partly with aponeuroses and muscular ligaments, partly with the true tendons. The chief *elastic ligaments* (fig. 81), are the *ligamenta subflava* between the arches of the vertebræ and the *lig. nuchæ*. The former are yellowish, very elastic, strong ligaments, the elastic elements of which, composed of rounded polygonal fibres of 0·0015‴ to 0·004‴ thick, united to form a close net-work, extend parallel to the long axis of the vertebral column, and occasion the longitudinally fibrous appearance of the ligaments. Between these fibres, which are disposed neither in the form of fasciculi nor in lamellæ,

Fig. 81.

A. Transverse section of a part of the *lig. nuchæ* of the ox, magnified 350 times, and treated with caustic soda. *a*. Areolar tissue appearing homogeneous. *b*. Transverse sections of the elastic fibres (of 0·004 to 0·01 of a line in diameter). B. *a*. Elastic fibres from one of the human *lig. subflava*, together with some areolar tissue, *b*, between them. Magnified 450 times.

but are connected throughout the entire thickness of a yellow ligament, there are found lax undulating fasciculi of connective tissue in small proportion. 3. *By Cartilage, Synchondrosis.* This mode of connection is effected by cartilage, either alone or along with fibro-cartilaginous and fibrous masses. The former occurs, in the adult, only in the ribs, of which, however, only the first is, properly speaking, connected to the sternum by a true synchondrosis; the remaining true ribs being connected, at their anterior extremities, by moveable articulations with the sternum, and the false ribs being partly articulated with each other, and partly ending quite free. The costal cartilages consist of the ordinary cartilage-substance, but exhibit, in certain places, a fibrous matrix, and for the most part cartilage-cells containing fat. In the *symphysis ossium pubis*, the *synchondrosis sacro-iliaca*, and the junctions of the bodies of the vertebræ, there exists, immediately upon the bone, a layer of true cartilage, which, in the two former localities, is connected with that of the opposite side immediately, but in the latter by means of a fibro-cartilaginous tissue, which, in the middle, forms a soft nucleus. They are surrounded externally by concentric layers of fibro-cartilaginous and fibrous substances. In the interior of these connecting substances, there frequently exists, in the two former instances, a narrow cavity, so that both, but more especially the sacro-iliac synchondrosis, may be regarded as a kind of joint.

The intervertebral ligaments are subject to various kinds of degeneration; they become ossified from their cartilaginous lamellæ outwards, so that two vertebræ are often found anchylosed; they become atrophied and brittle, and break down, either in the central portion, or in other circumscribed spots into a dirty pultaceous matter; finally, although they have no vessels in the normal condition, they seem to acquire them in a morbid condition; at least, effusions of blood are not unfrequently found in them in small spots near or in connection with the bone. The costal cartilages are very frequently *ossified* in old age: yet this ossification, as well as the fibrillation of their matrix, is not be regarded as a normal process, to be ranked with ordinary ossification. Their ossification is sometimes more limited, sometimes more extended. In the former case, it often does not go beyond the incrustation of the cartilage cells and matrix, which has become fibrous; in the latter (and frequently, too, in the former), the ossification is preceded by the formation of hollow spaces, and of a marrow with vessels, in the cartilage, which are partly connected with those of the perichondrium, partly with those of the osseous part of the ribs. The osseous substance is similar to the normal tissue, but almost always darker and less homogeneous, and its lacunæ, which often contain granular calcareous precipitates, are not so well developed. Under the name *cartilage-marrow*, are understood the marrow-cells, fat-cells, bundles of connective tissue and vessels, which appear in the place of the dissolved and abstracted cartilage-substance, and which may be said entirely to agree with those of developing fœtal bones, and may be readily observed in the ossifying costal and laryngeal cartilages.

B. *Connection by Articulation. Diarthrosis.*—The articular extremities of the bones, or such parts of their surface as enter into the formation of a joint, are covered with a thin layer of cartilage, which is firmly attached by a rough, depressed, or prominent surface to the bone; and, on the opposite side, is, in great part, naked and directed towards the articular cavity, but in part covered by a special coat — a perichondrium — which, as a prolongation of the periosteum, extends over a small part of the cartilage, and then gradually terminates without a well-defined border. In its intimate structure, articular cartilage presents a finely granular, in part, almost homogeneous matrix, and imbedded in this, thin-walled cartilage-capsules. These, at the surface, are numerous and flat, and lie with their planes parallel to it; further inwards, they become oblong or roundish, and more scanty, and are disposed in various directions; and, finally, in the vicinity of the subjacent bone, they are elongated and directed perpendicularly to it. All these capsules have distinct walls, which, especially on the addition of acetic acid, are readily distinguishable from the matrix, and contain in their interior, viz., in the primordial utricle, or proper cartilage-cell, a clear substance, often granular, but still with little fat, and vesicular nuclei. They are isolated or in groups, and very frequently contain two, four, or even more secondary cells, which, in the flat-cells, are disposed alongside each other, but in the elongated ones, in linear series. On the condyle of the lower-jaw and the glenoid cavity of the temporal bone, there is found, so long as the bone is not fully developed, a thick layer of well-marked cartilage capsules, covered towards the joint by a layer of connective tissue. This cartilage-layer shrinks away the more the bone approaches its full development, and at last there remains, under the layer of areolar tissue, which has become relatively and absolutely thicker, only a very

Fig. 82.

Perpendicular section of the articular cartilage of a human metacarpal bone; magnified 90 times. *a.* Most superficial flat cartilage-cells; *b.* central rounded; *c.* innermost cells, arranged perpendicularly and in small rows; *d.* outermost layer of the bone with ossified fibrous matrix, and thick-walled cartilage-cells rendered dark by included air; *e.* true bone-substance; *g.* medullary space.

thin and translucent layer, whose elements, although, morphologically, not true lacunæ, and also not ossified, are, nevertheless, much more nearly related to lacunæ than to cartilage-cells. According to *Bruch*, the covering at the sternal end of the clavicle is also fibrous. The part of the articular cartilage next to the bone presents an osseous layer, possessing, as *Sharpey* pointed out, the structure of cartilage but with the matrix calcified, and thus exhibiting, when decalcified, a different texture from that of the ordinary bone beneath (see also *Tomes* and *De Morgan*). The cartilaginous borders of the articular cavities principally consist of connective tissue, but invariably contain a few cartilage-cells. Articular cartilages, except during the period of development, as will be hereafter explained, contain no vessels or nerves.

In the fœtus, about the middle of embryonic life, the vessels of the synovial membrane are said by TOYNBEE (*Phil. Transact.*, 1841) to pass much further upon the articular cartilages; of which, however, in the humerus of five to six months' fœtuses, and also in new-born infants, I could not convince myself. In pathological conditions, endogenous cell-formations occur in remarkable perfection, and more especially in the velvety condition of articular cartilages, in which the mother-cells, frequently of very considerable size, with one or two generations of cells, and also containing fat, lie tolerably free in a fibrous matrix, and can be readily isolated. In adults, the articular cartilages are destitute of vessels, although the vessels of the synovial membrane, at their borders, often extend for some distance over them. That which LISTON (*Medico-Chir. Trans.*, vol. v., 2nd series. Lond. 1840, p. 93) describes as pathologically-developed cartilage-vessels, which pass from the bone in parallel lines into the cartilage, and then, after forming loops near the surface, return, are doubtless only the normal vessels of the cartilage, which are still well marked in individuals sixteen years old (see *infra*). Accordingly, we cannot admit the occurrence of inflammation of the cartilages in the adult; but they, no doubt, become altered in morbid conditions of the adjoining bone, or inflammations of the synovial membrane; they may split up into fibres, and this with increase of thickness, for CRUVEILHIER (*Dict. de Méd. et de Chir. Prat.*, iii. 514) saw the fibres six lines in length, which far exceeds the normal thickness of articular cartilages. They wear down readily, and, at last, entirely disappear (in suppurations of the bones or joints), so that the bones become denuded; they may also suffer partial loss of substance, so that ulcerous breaches are formed, which may penetrate to the bone, or proceed from it.

§ 95. The *articular capsules* are not shut sacs, but short and wide tubes, which are applied with their two open ends to the borders of the articular surfaces of the bones, and connect them. The articular capsule is, in some cases, attached simply to the border of the cartilaginous surface, and thence passes directly to the other bone (*patella, amphiarthroses*); in other cases, it also covers a greater or less part of the bone adjoining the cartilaginous surface, and is then reflected, in order to become connected with the other bone, in one of these two modes. In neither case does the synovial membrane rest immediately upon the hard structure, but is more or less closely adherent to the periosteum, and, finally, terminates, without a well-defined edge, not far from the border of the articular cartilage, with the perichondrium of which it is inseparably united. In point of intimate structure, the outer fibrous capsules entirely agree with the fibrous ligaments, whilst the synovial membranes consist 1.: of a layer of connective tissue with fine elastic fibres, and not very numerous vessels and nerves; and 2. of an epithelium composed of one to four layers of flattened cells, of 0·005‴ to 0·008‴ in diameter, with rounded nuclei. These membranes do not possess glands and papillæ, but they include in their folds *large collections of fat* (*plicæ adiposæ*), and are furnished with *vascular processes* (*plicæ vasculosæ*), or *synovial fringes*. The former, at one time improperly called Haversian glands, principally occur in the hip and knee joints in the form of yellow, or yellowish-red, soft processes or folds, and consist merely of large collections of fat-cells in more vascular parts of the synovial membrane. The latter exist in almost all joints; they are small flattened projections of the synovial membrane, of a red colour (if their vessels are full) indented and plaited at their borders, and beset with smaller processes. They are generally situated near to where the synovial membrane arises from the cartilage, and lie flat upon it, so that they often form a sort of wreath around it; in other cases they are more isolated, and also occur in other parts of the

Fig. 83.

Diagrammatic view of a section of a finger-joint, in part after *Arnold*. *a*. Bones; *b*. articular cartilages; *c*. periosteum passing into the perichondrium of the articular cartilages; *d*. synovial membrane at the border of the cartilage, beginning to become connected with the perichondrium; *e*. epithelium of the same.

joints. They consist almost solely of small arteries and veins, with capillaries connected at the borders of the processes in form of loops, and hence strikingly resemble the choroid plexus in the cerebral ventricles. Along with the vessels, they contain a fundamental connective tissue, often indistinctly fibrous; they are covered with an epithelium like that of the synovial membrane, and occasionally include fat-cells in smaller or larger numbers, and more rarely isolated cartilage-cells. On their border they almost invariably bear small, leaf-like, conical, membranous processes, of the strangest forms (often resembling a cactus-stem), which rarely contain vessels, and consist, for the most part, only of an indistinctly fibrous connective tissue along their axis, with, occasionally, one or two cartilage-cells and an epithelium very thick in some places. The smaller forms frequently consist only of epithelium, or almost solely of connective tissue.

The inter-articular cartilages or ligaments, and the ligaments of the joints, consist, with the exception of the soft *ligamentum teres*, of a firm connective tissue, with plasm-cells and fine elastic fibres, and occasionally, also, cartilage-cells, especially in the case of the first-mentioned structures. The *synovia* consists of a fluid containing mucus, and becomes turbid on the addition of acetic acid. It contains very frequently some epithelial cells which have undergone the fatty degeneration, the nuclei of such cells and compound granular cells. In conditions not entirely normal, blood and lymph corpuscles, and detached portions of the synovial fringes and articular cartilages, together with an amorphous gelatinous substance, are found in it.

The appendages of the synovial fringes, enlarging in size and acquiring a firmer consistence, may become detached from their connection, and thus give origin to certain forms of the so-called *loose cartilages* of joints. These, which also occur in the synovial bursæ and the sheaths of tendons, where, as well as in joints, the vascular processes exist, consist of connective tissue with elongated nuclei and a covering of epithelium, and contain, though not in all cases, a variable number of scattered fat-cells and true cartilage-cells. They are not developed externally to the synovial membrane, but are excrescences of the membrane itself. Moreover, it is probable that loose solid bodies may arise in another manner; at least, *Bidder* and *Virchow* have observed such bodies, which exhibited no trace of organised structure. I am disposed, with *Virchow*, to regard many examples of these latter, in which he has actually demonstrated fibrin, as consisting of fibrinous exudations, and others as consolidated precipitates from the synovia; and the latter explanation is supported by the fact of the frequent occurrence of amorphous gelatinous masses, of greater or less consistency in the tendinous sheaths of the hand, which concretions are evidently inspissated synovia. Pieces of bone, also, broken off from exuberant growths around the articular extremities, may escape into the interior of the joint.

§ 96. *Physical and Chemical Peculiarities of the Bones, and their Accessory Organs.*—The bones, besides containing a small quantity of water (according to *Stark*, 3 to 7 per cent. in the compact substance) and fat (2 to 3 per cent., *Bibra*), principally consist of a substance yielding gelatine and of inorganic constituents. In the adult, the latter constitute about two-thirds (68·82, *Bibra*) of the dry bone, and are almost all obtained by calcination. In this case, when proper precaution is taken, the bone completely retains its external form, but very readily breaks down into a white, opaque, brittle, heavy powder — the so-called bone-earth. This consists chiefly of 57 to 59 per cent. of tribasic phosphate, and 7 to 8 per cent. of carbonate of lime, some fluoride of calcium (traces), phosphate of magnesia, silica (traces), and alkaline salts. The substance of the bones yielding gelatine is the so-called bone-cartilage *(cartilago ossium)*, and constitutes about one-third of the dry bone. This is obtained by treating a bone with diluted hydrochloric or nitric acid, at a low temperature; it is a soft, elastic, yellowish, cartilaginous-like substance, which corresponds exactly to the shape of the bone, and yields, when boiled, ordinary gelatine.

The physical properties of the bones depend upon their composition. Their hardness, denseness, and firmness are due to the earthy, their elasticity and flexibility to the organic constituents. In healthy adult bones, the two main components are united in such proportions, that the bones, whilst sufficiently hard and firm, possess a certain, though small degree of elasticity, so that they have a considerable power of resistance, and do not so very readily break when subjected to mechanical violence. In early age, when the organic part is in larger proportion, their hardness, and, consequently, their capability of bearing weight, is much less; in this condition, they are more disposed to bend under pressure, whilst, on the other hand, their greater elasticity tends much to save them from fracture. This is the case, in a much higher degree, in rickets, where the organic constituents vary from between 70 and 80 per cent. In old age, on the contrary, the bones become harder, but, at the same time, more brittle, so that they break very readily, although their greater fragility may be partly owing to the rarefaction of the tissue which takes place at this period. The combustibility of the bones is due to their organic basis; their opacity, white colour, high specific gravity, and resistance to putrefaction, to their inorganic components. The latter, being so intimately blended with the animal constituents, protect these also; and, accordingly, bones from ancient graves, and those of fossil animals, still retain their original proportion of cartilage.

The *true cartilages*, and also those of the fœtus, contain, in addition to their organic basis, 50 to 75 per cent. of water, and 3 to 4 per cent. of salts (chiefly salts of soda and carbonate of lime, with a little phosphate of lime and magnesia). The organic matter forming the matrix consists of chondrin, or cartilage-gelatine; but the cartilage-capsules, and the cells which they enclose, are insoluble in water, and resist the action of caustic potass and sulphuric acid for a longer period than the matrix, so that their composition appears to be different, and peculiar to themselves.

§ 97. *Vessels of the Bones and Accessory Parts.* A. *Blood-vessels.* — Besides the numerous vessels passing through it on their way to the bones, the periosteum is furnished with a moderately close network of capillaries, of 0·005‴ in diameter, situate chiefly in its outer layer. The blood-vessels proper to the bone are very numerous, as may be seen in injected preparations, and still more readily in fresh bones, in which they are filled with blood. In the *long bones*, the medulla, the spongy articular extremities, and the compact substance of the shaft, are all nourished by special vessels. Those of the medulla, or the *vasa nutritia*, pass into the bones through special canals, one or two in number in the diaphyses, but more numerous in the apophyses; and, after bestowing a few small vessels to the innermost Haversian canals of the compact substance, ramify in the medulla, and then form a genuine network of capillaries, of 0·004‴ to 0·0052‴ in diameter. The vessels of the compact substance come, for the most part, from those of the periosteum, very soon lose their muscular coat, and form in the Haversian canals, which are sometimes destitute of other contents, sometimes contain a small quantity of marrow, a network of wide canals. Of these canals, only a very small number can be regarded as capillaries, seeing that the majority of them possess a layer of areolar tissue and an epithelium, and that fine capillaries are present only in the larger Haversian canals, along with the main vessel. The venous blood passes out of every long bone at three places: 1. by a large vein which accompanies the arteria nutritia, and has the same distribution; 2. by numerous large and small veins at the articular extremities; 3. by many small veins, which arise independently from the compact substance of the shaft, in which their roots, as *Todd* and *Bowman* correctly pointed out, occupy the wider spaces and the sinus or pouch-like excavations, as may be well seen in polished sections of the bones. All the vessels, both the medullary vessels of the apophyses and diaphyses, and the vessels of the compact substance, communicate in various ways, so that the vascular system forms one continuous whole throughout the entire bone, and the blood is enabled, possibly, to flow from any one part to all the others. *Bichat* accordingly (iii. 44), found the medulla very well injected in an injected tibia, the nutrient arteries of which were obliterated.

In the *short bones*, the blood-vessels present the same relations as in the apophyses of the long ones. This is also the case with the *flat bones;* only the scapula and innominate bone possess special nutrient foramina for larger arteries and veins, and in all cases their compact substance receives its finer vessels from the periosteum. In the flat cranial bones, the veins, or *venæ diplöeticæ*, have only their roots free in the marrow, as in other bones; their trunks, branches, and larger ramifications, on the other hand, run separately, mostly, without being accompanied by medulla, in special, arborescent larger canals, the so-called Breschet's bone-canals, which terminate at fixed places by large apertures *(emissoria Santorini).* With regard to the vessels of the cartilages of the osseous system, and of the synovial membranes, see §§ 94 and 95.

B. *Lymphatic vessels* have been observed in no part of the osseous system with certainty, except in the loose areolar tissue around the articular capsules, and between the latter and the periosteum of the apophyses, especially at the knee-joint.

§ 98. *Nerves of the Osseous System.*—The periosteum is rich in nerves, and although the greater part of them are destined for the subjacent bone, nevertheless, apparently, in all bones there are nerves which ramify in the membrane, occasionally presenting divisions of the primitive tubules, and terminating by free extremities. These nerves are most numerous at the articular extremities of the bones, especially at the knee.

The bones themselves, with, perhaps, the exception of the *ossicula auditus* and *ossa sesamoidea,* all contain a considerable number of nerves. These pass into the bones partly with the nutrient arteries, and ramify in the marrow, partly supply the spongy substance of the articular extremities of the long, short, and flat bones. They are most numerous in the apophyses of the large cylindrical bones, in the vertebræ, and the larger flat bones.

With regard to their origin, they come partly from the cerebral and spinal nerves, partly, also, from the sympathetic. They all possess dark-bordered tubules, and, finally, run out into fine branches with one to two primitive fibres, the termination of which has not yet been ascertained. In man, no nerves have hitherto been found in the ligaments; but the *ligamentum nuchæ* of the ox contains some fine nerve-fibres. On the other hand, the *membrana interossea cruris* possesses fine nerve-filaments, which come from the anterior tibial nerve. Of the cartilages, I have hitherto observed only in the cartilaginous septum nasi of the *calf* very distinct fine nervous trunks of 0·006‴ to 0·01‴ in diameter, with fibres of 0·0012‴ to 0·0016‴ in thickness, along with the vessels (arteries) in the cartilage-canals. In the articular capsules there exist numerous nerves, yet they belong chiefly to the so-called fibrous capsules and the loose areolar tissue, external to the synovial membranes; it is only in the knee-joint that I have seen nerves in the proper synovial membrane.

§ 99. *Development of the Bones.*—The bones, with reference to their development, may be divided into two groups, viz., into those *preformed in a cartilaginous condition* (primary bones), and into those which, *from a small beginning, are gradually developed in a soft blastema* (secondary bones). The former, even in their cartilaginous condition are furnished with all their essential parts (diaphyses and apophyses, bodies, arches and processes); and as far as their cartilaginous basis is concerned, are developed like other cartilages, and like these, also continue to grow more or less. They then ossify; a part of the cartilage is completely transformed into bone, its perichondrium being converted into periosteum; and from this period onwards, they attain their ultimate form, partly at the expense of the remaining cartilage, which continues to grow with them, and to ossify successively, and partly by soft ossifying blastema, which is deposited layer after layer upon the inner surface of the periosteum. The second group of bones are formed from a very limited, soft, non-cartilaginous basis, and enlarge at the expense of the latter, which, at first, extends itself only at its borders, but soon also increases at its surfaces. When these bones have attained a certain size, the blastema, by means of which they had hitherto enlarged, may be partially converted into cartilage, and the cartilage so produced enter into the same relation with them, as in other cases. The chief part of their formative substance, however, remains soft, and the main mass of the bone arises from it immediately, without having ever been cartilaginous.

Although the development of the osseous *tissue* has often been treated of, yet the manner in which the bones originate as *organs* has met with but little attention; and in 1849 and 1850, *H. Meyer* and I were the first to follow them in detail, after the principal features had been ascertained in 1846-47 by *Tomes*, *Sharpey*, *Bowman* and me (*Zürich. Mitth.* i. p. 168). Quite recently, *Bruch*, *Virchow*, *Brandt*, *Tomes* and *De Morgan*, and *H. Müller*, have furnished valuable additions.

§ 100. The *original cartilage-skeleton* of the human body is less complete than the subsequent bony one, but is, nevertheless, tolerably well developed. We find, as parts of it, 1, a complete vertebral column, with the same number of vertebræ as in the osseous one, with cartilaginous processes and intervertebral ligaments; 2, cartilaginous ribs, and a cartilaginous, non-segmented sternum; 3, entirely cartilaginous extremities, of the same number and external form as the subsequent bones, with the single exception of the pelvic cartilage, which constitutes a single mass, and the clavicle, which never exists in the cartilaginous state (*Bruch*); 4, an imperfect cartilaginous skull. This so-called *primordial cranium* forms originally a continuous cartilaginous substance, corresponding chiefly to the occipital bone (with exception of the upper half of the flat portion), the sphenoid bone (except the external lamina of the pterygoid process), the mastoid and petrous portions of the temporal, the ethmoid, the inferior turbinate, the ossicles of the ear and the hyoid bone. It also contains some *cartilaginous* parts which never ossify; these either remain in this condition during the whole period of life, as the most of the cartilage of the nose, and the lesser cornua of the hyoid bone, or subsequently disappear, as is the case with what is named Meckel's process; also two cartilaginous lamellæ beneath the nasal bones, and a slender cartilage which connects the styloid process with the hyoid bone. Consequently, the vault of the skull, and almost the whole of the lateral portions are absent in the human *cartilaginous* cranium; further, almost all the part subsequently occupied by the facial bones; but at the parts not formed from cartilage, the cranium is closed in and completed by a fibrous membrane, which is but a further development of the primitive soft skull-capsule. Thus the skull, although only in part cartilaginous, is as complete at this period as formerly, and in this respect still corresponds to its original condition. The cranium is more completely formed of cartilage in some quadrupeds, as, for example, in the pig and mouse (see my *Mikrosc. Anat.*).

The cells of the cartilage are developed from the primitive embryonic cells which, while they become larger, develop an interstitial substance between them. The whole embryonic and subsequent growth of the cartilage, is owing to the increase of this intermediate substance and the multiplication of the cells (see § 11). The cartilage-cells of the adult, accordingly, are the descendants of the primitive embryonic-cells.

§ 101. *Metamorphoses of the Primitive Cartilaginous Skeleton.*—Of the primitive cartilages, some are further developed with the other portions of the skeleton, and become the permanent cartilages of the nose, joints, symphyses, and synchondroses; a few disappear in the course of development (certain cranial cartilages, see § 100); but the greatest number finally ossify and form the first rudiments of the bones of the trunk and extremities, and of a considerable portion of those of the skull. All these bones ossify in essentially the same manner. At one or more points (*puncta ossificationis*), a deposition of calcareous salts begins in their interior contemporaneously with an alteration of the cartilaginous elements; and this metamorphosis, advancing in some or in all directions, continually converts more cartilaginous parts into bone. While this takes place, the cartilage, in most cases, ceases to grow in one direction, and, consequently, is soon wholly converted into bone, but extends itself in other directions, and thus continually furnishes new formative material to the advancing bone, and may become the seat of new centres of ossification, as in the epiphyses of the cylindrical bones. Still the bone, after it has invaded the whole of the cartilage, and converted its perichondrium into periosteum, does not cease enlarging; but from this period to that of completed growth, a new and peculiar method of formation takes place in all these places. This consists in the ossification of an organised soft formative substance, situate upon the inner surface of the vascular periosteum, and formed from it; the ossification proceeding from the surface of the bone outwards through the soft substance, which in proportion as this takes place, is continually reproduced from the periosteum.

Recent observations of *H. Müller* show that the first ossification in the diaphyses of the long bones of the calf takes place in the *outermost parts of the cartilage*, if not in the periosteal layer itself. The first rudiment of the femur, for instance, has therefore the form of a short tube surrounding the primordial cartilage. Further observation will show how the ossification proceeds in this animal. The same fact had, however, been observed by *Howship*, in the case of the metacarpal and phalangeal bones of the human embryo, and he inferred that the cylindrical bones of mammalia generally follow this rule. (*Medico-Chir. Trans.* 1819. Vol. vi. pp. 264 and 283, and Pl. i. fig. 1.)

§ 102. *Alterations in the Ossifying Cartilages.*—At the period of the ossification of a cartilage, its cells, which were hitherto small, and contained but few secondary cells, begin to enlarge, and new generations of cells are successively produced from the previously existing ones. This active vegetative process also manifests itself at the ossifying borders of the bones, which are already developed to some extent, where the cells next to the bone are found to be larger, and are smaller the further they are removed from it. All cells about to become ossified, possess only moderately thick capsules, and a distinct primordial utricle (cartilage-cell) with clear, rarely somewhat granular contents, along with a distinct vesicular round nucleus, possessing a nucleolus and readily distinguishable walls. They alter, however, very quickly on the addition of water, acetic acid or alcohol, or by dessication, etc., the contents and membrane of the primordial utricle contracting around the nucleus, and forming a rounded, elongated, dentated, even stellate, granular, dark body (cartilage-corpuscle of authors). Their *size and the manner in which they are grouped*, varies not inconsiderably according to age and locality. With regard to the first point, they exhibit a continual increase during embryonic life, whilst after birth, their size appears to remain nearly the same. With reference to arrangement, it is a law, that wherever cartilages ossify only in one direction, the cells, at the border of the bone, are arranged in *rows*. As has been long known, this is best marked at the ends of the diaphyses of cylindrical bones, where the rows lie very beautifully and regularly parallel to each other, and are of considerable length. This arrangement may also be seen in many other places, as soon as cartilages ossify only in one direction, as, for instance, upon the surfaces of connection of the vertebræ. Where, on the other hand, the osseous centres in the midst of a cartilage, enlarge in all directions, the cartilage-cells are gathered into rounded, or oblong, irregularly scattered groups, as in the short bones at the time of their commencement, and in the epiphyses.

By closely comparing the cells which lie nearer, and those further removed from, the borders of ossification, and the separate groups which they form, it becomes evident, that their peculiar arrangement is directly connected with the manner of their multiplication. Every separate group (or two) corresponds, in a certain measure, to a single original cell, and represents all the descendants which, in the course of development, have sprung from the latter. Now, in some cases, all these newly-formed cells are disposed in one or two rows, and, when they have grown further, give rise to the above-mentioned oblong group, whilst in others they form a more spherical mass. During these changes, the original cells (primitive mother capsules), sometimes, through coalescence of their outer cell-membranes with the surrounding matrix, cease to exist as peculiar structures, sometimes not; and the same holds good with those of later generations. The rounded groups of cells being smaller, usually retain their original inclosing capsule, which, now greatly dilated, may be recognised as a contour line surrounding them; but when the cells are arranged in rows, the membrane of the original capsule is so blended with the adjoining matrix, as to be no longer distinguishable. The entire layer, which the above-described, enlarged and multiplying cells, occupy, varies in thickness in different cartilages. It is thin around the points of ossification of the epiphyses and short bones; ¼ to ½ a line upon the diaphyses. By its yellowish translucent colour, and its striated, apparently fibrous matrix (*Brandt* saw this also homogeneous), it is everywhere distinguished from the other parts of the cartilage which are, as usual, bluish-white, with homogeneous or granular matrix.

Fig. 84.

Perpendicular section from the border of ossification of the diaphysis of the femur of a child two weeks old; magnified 20 times. *a*. Cartilage, the cells of which, the nearer they approximate to the border of ossification are arranged in longer longitudinal rows. *b*. Border of ossification, the dark stripes indicate the ossification taking place in the intercellular substance, the clear lines, the cartilage-cells which ossify at a later period. *c*. Compact bone near the border of ossification. *d*. *Substantia spongiosa* with medullary spaces, *e*. produced by the absorption of developed osseous substance, whose contents are not exhibited.

The appearance and progress of *vessels* in ossifying cartilages is an interesting phenomenon. They are found, in many places, from the middle of fœtal life onwards, preceding, for a shorter or longer time, the appearance of the points of ossification, and accompany these in their growth. I have observed them, even, in the articular cartilage of the epiphyses of the long bones of a person sixteen years old. These vessels invariably lie in wide canals, excavated in the cartilage and bounded by elongated narrow cartilage-cells. These *vascular canals of the cartilage*, or *cartilage-canals*, pass into the cartilage from the perichondrium, and when a vascular point of ossification is present (diaphysis) also, from the border of ossification; but there in smaller number, at least in early stages. They ramify in the cartilage in various directions, and without appearing to form anastomoses or other connections, apparently end in blind and mostly club-shaped extremities. These canals originate by a transformation of the elements of the cartilage, like the medullary spaces of the bones themselves; they at first contain a formative substance (cartilage-medulla), composed of small round cells, corresponding to the fœtal bone-marrow, out of which, in a short time, are developed true sanguiferous vessels and a limiting wall, consisting of more or less developed connective tissue, and, subsequently, also of elastic fibres. I have found sometimes only one larger vessel (often very distinctly arterial in character, with muscular walls), sometimes two, sometimes capillaries in variable number, in one canal; but I am unable to say how the circulation is performed in these vessels. Either anastomoses must take place between the vessels of different canals; or when the latter are in reality shut, there must be arteries and veins in one and the same canal. The purpose of these cartilage-vessels appears to be two-fold: first, and more especially, to supply the cartilage with materials necessary for its growth and further development; secondly, to promote the process of ossification. The former is very obvious in the thick cartilages of epiphyses, which continue growing for a long period before they ossify, and even after this do not cease enlarging; the latter is, perhaps, best exemplified in the short bones, which do not receive vessels until immediately before their ossification commences.

The more intimate changes occurring in the formation of the cartilage-canals and cartilage-marrow have hitherto been but little investigated. *Virchow* (*Arch.* v. p. 428) believes he has seen in bones affected with rickets the cartilage-matrix and the capsules becoming streaked and opaque, whilst the cartilage-cells, or primordial utricles, became larger and more granular, and exhibited a multiplication of their nuclei. The matrix, so altered, then passed gradually into undoubted medullary substance, which here and there still enclosed distinct remnants of cartilage, and was composed, for the most part, of larger and smaller granular cells with one or several nuclei, and of the above-mentioned matrix. I agree in all points with the opinion of this author, and have followed the origin of the small cells of the marrow from the cartilage-cells and their metamorphoses into the subsequent contents of the cartilage-canals.

§ 103. *Ossification of the Cartilage.*—The ossification of the matrix generally precedes that of the cartilage-cells, and, in normal conditions, is effected by granular precipitates of calcareous salts—the so-called calcareous granules. Wherever rows of cells exist at the ossifying border, these deposits, when viewed in longitudinal sections, are seen in the form of pointed processes running into the fibrous substance between the rows, and enveloping the lowermost parts of the latter in form of short tubes. Essentially the same process is seen in other places, where the cartilage-cells are arranged more in the form of rounded groups, except that here the ossifying matrix surrounds the latter more in form of a network. If, in microscopical sections, the granules be followed from the border of ossification into the interior of the young bone, it is seen that the latter, although with decreasing distinctness, still exhibits, for a certain distance, the granular and dark appearance of the border itself, then gradually becomes more uniform, clearer and more transparent, and, finally, assumes nearly the same appearance as the fully developed bone. To all appearance, the primitive granules gradually coalesce with each other, and thus impregnate the whole tissue of the cartilaginous matrix, instead of only separate parts of it, as at first, and, accordingly, cease to exist, or to be distinguishable as isolated particles.

With regard to the *formation of the lacunæ* from the cartilage-cells, there exists a very remarkable difference between rachitic bones and normal structures. In rachitic bones, as I have shown, the lacunæ are formed from the cartilage-capsules by the thickening and ossification of their walls with the contemporaneous formation of canalicular spaces in them; whilst, at the same time, the primordial utricles, or cartilage-cells, enclosed by them, are transformed into the stellate bone-cells of *Virchow*. In the ossifying diaphysis of a rachitic bone, the morphology of this process can be most beautifully observed. If the linearly-arranged, large cartilage-capsules of the ossifying border be followed from without inwards, it is soon found that, where the deposition of calcareous salts (which in this case is generally effected without the formation of granules) begins, they exhibit, instead of a membrane indicated

Fig. 85.

Six developing bone-cells from a ricketty bone, as yet sharply defined from the interstitial substance. *a*. Simple bone-cells; *b*, a compound one, answering to a parent cell with two secondary cells; *c*. similar ones with three cells. Magnified 350 diameters.

by a single, moderately-thick line, a thicker coat, which presents delicate indentations upon its inner side. When this has attained only 0·001‴ in thickness, it may already be perceived that the cavities of the cartilage-capsules are in the act of being transformed into lacunæ; and this process becomes still more distinct farther within the bone. The thickness of the membrane in question, together with the diminution of its cavity, is seen to increase more and more, the indentations of its inner boundary line become more pronounced, and, contemporaneously with these changes, the walls become darker and darker, from the deposition of calcareous matter. The slow ossification of the matrix between the capsules very much facilitates the observation of all these changes, and permits not only the first metamorphoses of the cartilage-capsules to be very narrowly investigated, but also their subsequent conditions, at a time when they must be called bone-capsules and lacunæ. To this circumstance alone is to be ascribed the establishment of the interesting fact, that cartilage-capsules which enclose secondary cells pass, in their totality, into a single *compound bone-capsule*. Very frequently such bone-capsules are found with two cavities, which, according to the degree of their development, are sometimes wide and furnished with short processes, sometimes present narrow cavities and longer canaliculi, and resemble completely the fully-developed lacunæ. Compound capsules, with three, four, and five cavities, are more rare, still they also occur here and there in almost every preparation. In all these cartilage-capsules, and in the bone-capsules originating from them, there are not only, as I formerly believed, the remains of the original cell-contents together with the cell-nuclei, but also the original cartilage-cells, or primordial utricle, only it is smaller. Since, in perfectly fresh objects, it accurately fills the cavity of the cartilage-capsule, it will, perhaps from the beginning, project by means of delicate processes into the pore-canals of the thickened capsule, still I have not yet succeeded in observing them as stellated bodies in the earlier stages of development; while, on the other hand, this is extremely easy in the latter, by macerating them in hydrochloric acid. When the cartilage-capsules have, in the manner above stated, passed into distinct bone-capsules, containing delicate cells and other contents, but lying free in the unossified matrix, the final alterations take place, in consequence of which the ricketty bone-substance assumes pretty nearly the nature of the healthy tissue. These changes chiefly consist: first, in the matrix beginning to ossify, and without primitive calcareous granules; and secondly, in the more and more abundant deposition of calcareous matter in the matrix and the thickened walls of the bone-capsule. In consequence of this process, the new osseous substance becomes whiter and whiter to the naked eye, and appears, under the microscope, darker and more transparent. It also becomes more homogeneous, and the sharp outlines of the bone-capsules get more and more faint, till at last they appear not as cellular bodies lying free in the matrix, but coalesced with the latter, being recognisable only by their peculiar stellate cavities—the so-called bone-corpuscles, or lacunæ, and canaliculi, together with *Virchow's* bone-cells enclosed by them.

If, after becoming acquainted with the process of the formation of the lacunæ in the rachitic bone, we endeavour to obtain an insight of that in the normal bone, it is not found so difficult as formerly, when hypotheses the most various, and without reliable basis, were current. Still the investigation of the point in question in human bones, as well as in those of animals, during development, is very laborious, and often yields but small return. It may here with certainty be seen (see my *Micr. Anat.*, tab. iii.), that the cartilage-capsules, a little within the border of ossification, become thickened and occupied with calcareous granules, whilst their cavities and contents still remain partially visible. The capsules so encrusted may also be isolated; but the manner in which the alterations further proceed cannot be seen with nearly the same definiteness as in rachitic bones, since further inwards the young medulla, with its vessels and the calcareous granules, render almost everything indistinct; and it is only in the parts of the bone which have become homogeneous and more transparent, that lacunæ — by this time almost completed — can be clearly distinguished. Nevertheless, according to all that we observe, there cannot be the slightest doubt, that the processes are essentially the same as in rachitic bones, only that the ossification of the thickened walls of the cartilage-capsules goes through two stages, instead of only one, inasmuch as they are at first granular, from the deposition of calcareous particles, and then become homogeneous. Moreover, even in the perfectly normal skeleton of the adult I have found some places, viz., the symphysis pubis, the intervertebral disks, and the sacro-iliac synchondrosis, where, at the boundary between the cartilage and the bone, cartilage-capsules of the most beautiful description, and in the most various stages of transition into bone-capsules, may be seen, lying *free in the matrix of the cartilage;* some have thickened walls, with more or less deposition of calcareous granules, whilst others are almost fully-developed bone capsules, with pores and a more homogeneous wall.

I can thus support my above-mentioned assertion, of the development of the lacunæ from the cellular elements of the cartilage, by what may be seen under normal conditions. In the last-mentioned places, I observed very frequently, also, half and completely ossified mother-capsules, with from two to twelve included secondary capsules of the most beautiful description.

The development of the *medullary spaces* and of the *bone-marrow* is, in a certain measure, the last act in the transformation of cartilage into bone. The medullary spaces originate not by the coalescence of the cartilage-cells, but by the solution of the more or less developed osseous substance, exactly in the same manner as the large medullary cavities of the cylindrical bones. This can be most distinctly proved by examining the diaphyses of a healthy or rachitic bone, especially the latter. At the border of ossification (fig. 84), the osseous substance is, for the distance of about $\frac{1}{5}'''$ to $\frac{1}{3}'''$, quite compact, without a trace of larger cavities, and is here composed partly of ossifying matrix, partly of cartilage-capsules, more or less changed into lacunæ (see *Micr. Anat.*, tab. iii.). Then there come, first smaller, and further onwards, larger cavities, the characters of which, in every respect, show most convincingly that they do not owe their origin to the evolution or expansion of previously formed parts. They are bounded by very irregular contours, which often appear as if eroded; they are generally larger than the cartilage-capsules, oval, or rounded and angular, and disposed without any trace of regularity in the new-formed compact bony substance. If the borders and bounding surfaces of these spaces be narrowly examined, it is easy, in many cases, to recognise more or less eroded bone-corpuscles, half projecting from or imbedded in the walls, and, between these, projections of the ossifying matrix, so that not the slightest doubt can remain as to their origin.

As in the diaphyses, so in the ossification of all the other cartilages, medullary spaces are formed by absorption within the half-ossified substance, only it is to be observed that these spaces do not exhibit the same direction and size in all the bones; but it is unnecessary to dwell further on this matter, since the conditions of this primitive spongy substance is, in its main features, the same at later periods. Still, it may be remarked, that probably in many bones medullary spaces are developed directly from the cartilage canals, since, at the border of ossification, a part at least of the latter stands in direct connection with the spaces in the bone; and further, that in many cases cartilage-elements, which have not yet been completely converted into bone-capsules, are involved in the process of resolution. With regard to this latter point, it seems that in certain cases not one cartilage-cell is converted into a real bone-corpuscle, with branched processes; and it may be recalled to mind, that many years ago *Sharpey* promulgated the opinion, that all bone-corpuscles in the bone formed from cartilage are secondary formations, formed at the parietes of the medullary spaces, — a view which is also maintained nearly in the same manner in the recent investigations of *H. Müller.*

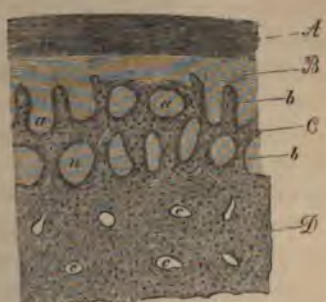
The medullary spaces, however they arise, become filled with a soft reddish substance, the *fœtal* marrow. At first, this consists of nothing but some fluid, and numerous rounded cells with one or two nuclei and slightly granular contents. After a time, these cells, which are quite identical with those occurring in certain bones in the adult (see above), become developed in the usual manner into connective tissue, blood-vessels, fat-cells, nerves, and bone. *The formation of the blood-vessels* proceeds very rapidly, so that, a short time after the development of the medullary spaces, the bones already possess blood-vessels; the fat-cells and the nerves are more slowly formed, yet at the period of birth, they are very readily seen in the large cylindrical bones. At this period the fat-cells are but few in number, the marrow, in man, at least, being still quite red from the presence of blood and the slightly reddish-coloured marrow-cells. After birth the fat-cells gradually multiply, till at last the marrow, in consequence of their great increase, and of the disappearance of the marrow-cells, all of which are finally resolved into the elements of the permanent marrow, assumes its subsequent colour and consistence. A great part of the cells of the new-formed marrow of developing bones are transformed into bone, and thus serve to thicken the rudimentary bone-lamellæ, which took their origin from the cartilage.

Disputes still prevail in various quarters about the development of the lacunæ from the cartilage-capsules, yet I believe that my original description (*Zürch. Mitth.*, 1847), which has been confirmed by ROKITANSKY and VIRCHOW (*Würzb. Verh.* ii., and *Arch.* v. p. 431), is, as now modified, still the most tenable. In the publication mentioned, I described the contents of the bone-lacunæ and cartilage-capsules as simple cell-contents, so that when *Virchow* had demonstrated the direct transformation of plasm-cells into bone-cells, it appeared almost impossible to harmonise my observations upon rachitic bones with the latter. Now if, as held by *Remak* and me, the ossifying cartilage-capsules be regarded as secondary cell-membranes, and their contents as primordial cells; and if the latter be admitted to grow out in a stellate manner during the ossification, the harmony between the formation of the lacunæ from the cartilage-capsules and plasm-cells is restored in all essential points. If the opinion of *Sharpey* and *H. Müller* be correct, that in normal ossification none or very few of the cartilage-corpuscles are directly metamorphosed into bone-cells, and that the latter take their origin from the cells of the first-formed medulla, then there would be no difference in the formation of bone-cells from cartilage and from the periosteal layers, as, indeed, *Sharpey* maintained long ago.

With regard to the origin of the marrow-cells, *Virchow* is of opinion, that they arise from the cartilage-cells enclosed in the ossifying cartilage-capsules, which, by their multiplication, produce the small cells of the primitive marrow; whilst the latter is, in turn, transformed into fibres, vessels, nerves, fat-cells, etc. According to what *H. Müller* has seen, there can be no doubt that this view is correct. Hence it follows, that the bone-cells in bone formed from cartilage, at all events, originate from cells which are the descendants from the original cartilage-corpuscles.

§ 104. *Changes in the Sub-periosteal Deposit.*—The periosteum of the bones which commence by cartilage is relatively very thick and vascular, and, even in the fifth month of fœtal life, consists of ordinary connective tissue and fine elastic fibres; the latter, as the development advances, becoming thicker and thicker, and occasionally assuming the nature of thicker elastic fibres. Upon the inner side of the fully-developed periosteum, there is an *ossifying blastema* firmly adherent to the bone (fig. 86), so that when the periosteum is pulled off, it generally remains lying upon it in the form of a moderately thick, soft, whitish-yellow lamella, which, when examined microscopically, presents a fibrous tissue with somewhat indistinct fibrils, like immature connective tissue, and granular, oval, or round nucleated cells, of 0·016‴ to 0·01‴ in size. If this lamella be raised from the bone, it is found to be very intimately connected with the most superficial layers of the latter; and upon its inner side, detached osseous fragments and portions of reddish, soft marrow, from the most superficial bone-spaces, are usually met with. The denuded bone, when the lamella has been cautiously

Fig. 86.



Transverse section, from the surface of the diaphysis of a metatarsal bone of the calf; magnified 45 times. A. Periosteum. B. Ossifying blastema. C. Young bone-deposit, with wide spaces (*a.*), in which remains of the ossifying blastema still exist, and reticulated trabeculæ (*b.*), which are rather sharply marked off from the blastema. D. Further developed bone with Haversian canals (*c.*), surrounded by their lamellæ.

and successfully detached, has a rough and, as it were, porous surface, with numerous medullary spaces; and, in its outermost part, is, for a greater or less extent, still quite soft, pale yellow, and translucent; further inwards, on the contrary, it continually increases in firmness and whiteness, till at last it assumes the usual appearance of fully-developed bone. The formation of bone, which undoubtedly here takes place, is effected through means of the above-mentioned blastema, the cells of which, scattered among the delicate fibres, have not the slightest resemblance to cartilage-cells, but have exactly the same appearance as fœtal marrow-cells, or the formative cells of the embryo. In fact, it is now not very difficult to demonstrate, that the outermost, still soft osseous layers, with their trabeculæ and projections, pass into the blastema in question; and that, 1st, the fundamental substance of the bone arises from its fibrous tissue by the simple uniform deposition of calcareous salts, but, as it would seem, without the previous appearance of calcareous granules; and 2nd, that the bone-cells become developed from the formative-cells of the blastema; still, with reference to the latter, the metamorphosis cannot be followed step by step, as in the rachitic bones. According to *Virchow's* discovery, which I can fully confirm, these cells, without previously presenting secondary membranes, like the cartilage-capsules, gradually acquire a stellate form, and, when the surrounding matrix ossifies, become directly transformed into stellate bone-cells, which, accordingly, are not contained in bone-capsules. With reference to the development of the ossifying blastema itself, see the note at the end of this section.

The formation of bone in the above-mentioned blastema occurs in all places where the latter is in connection with the bone; it does not, however, take place in *uniformly continuous* but *in reticulated interrupted lamellæ*. The rounded and elongated spaces (fig. 86 *a*), which from the first remain in the intervals of the osseous tissue, and communicate with each other in the different layers, are in reality the *rudiments of the Haversian or vascular canals* of the compact substance, and contain soft reddish medulla, which, at first, is evidently merely the non-ossifying portion of the ossific blastema, but soon contains more formative cells than connective tissue. The cells of these spaces soon take on the form of ordinary, slightly reddish marrow-cells. A part of them are also transformed into vessels which communicate with those of the interior of the bone, and especially also with those of the periosteum, with which, having once entered into connection, they remain in communication during the whole period of the increase in thickness of the bone; so that the formation of the gaps or cavities of the bone is, at least afterwards, pre-indicated by these vessels, which, according to what we have said, pass from the periosteum through the ossifying blastema to the bone. Besides marrow-cells, vessels and a small quantity of connective tissue, the bone-cavities of the periosteal layers also contain round, elongated or dentated, flattened, slightly granular, cell-like bodies of 0·01‴ to 0·02‴, and more in size, with 3 to 12, and more vesicular nuclei and nucleoli, which are probably to be ascribed to a multiplication of the marrow-cells.

The periosteal layers, which, according to what we have stated, are deposited as cribriform interrupted lamellæ around the osseous masses formed from the cartilages, continue to be formed in the same manner, as long as the bones grow, and occasion their *increase in thickness*. At the same time, more or less essential alterations take place in them, and more especially in the *large cylindrical bones*. In these we find, that gradually, but more evidently from and after birth, a large cavity becomes developed in the interior, which at first is filled with fœtal marrow-cells, and subsequently with fully developed medulla. This medullary cavity is formed in the same manner as the medullary spaces described in the previous paragraph, by solution of the osseous substance of the middle portion of the shaft, at first only of that which has arisen from the primitive nucleus, soon also of that deposited by the periosteum upon the former, and thus continues to enlarge in a remarkable manner as long as the bone continues growing. Whence it happens, that, both at the ends of the diaphyses, and at their circumference, *whilst new bone is continually deposited externally, that already formed is uninterruptedly absorbed from within outwards*. Indeed, these two processes are so combined, that the bone during its development is, so to speak, several times regenerated, so that, for example, the humerus of the adult does not contain an atom of the osseous substance of that of the new-born infant; and, again, this latter contains nothing of that of the embryo of three months. These relations, as well as those of the periosteal and cartilage layers, to one another, will be better understood with the aid of a diagram (fig. 87). If we here compare the primitive bone EE with the almost fully developed one $E^4 E^4$, it is seen, that in the longitudinal growth of the diaphyses of the latter on both sides, at the expense of the continually growing epiphysal cartilage, an elongated cone of osseous substance, 1, 2, 1′, 2′, and 3, 4, 3′, 4′, has been produced, to which, then, the epiphysal nuclei E^4E^4, likewise originating in the cartilage, are added, whilst in its growth in thickness, the cylindrical layers P, P^1, P^2, P^3 which become continually longer and, in the middle, thicker, are concerned. In such a cylindrical bone, accordingly, all the part formed from cartilage has the form of a double cone with rounded bases, the part deposited from the periosteum 1, 2, 3, 4, P^3, and 1′, 2′, 3′, 4′P^3, that of a long tube thickest in the middle, similar to an elongated vertebra of a fish with conically depressed end surfaces. The articular cartilage G is the non-ossified remains of the epiphysal cartilage and the medullary cavity not exhibited in the figure (it can be imagined as nearly indicated by the contours of the fourth bone E^3E^3) has arisen by the absorption of the whole osseous substance developed from the cartilage and periosteum; in this case the first three EE, E^1E^1 and E^2E^2. In the cylindrical bones without a medullary cavity, and in all others which contain only spongy substance in their interior, the absorption does not advance nearly so far as in the above-described cases; that is to say, it proceeds only to the production of a loose spongy substance in the interior, and we find accordingly, for instance in the vertebræ, still more or less considerable remains of the earlier bone deposits, even of those which have arisen from the ossification of cartilage. The absorption here also affects not only the osseous nucleus formed from the cartilage, but also the periosteal

Fig. 87.

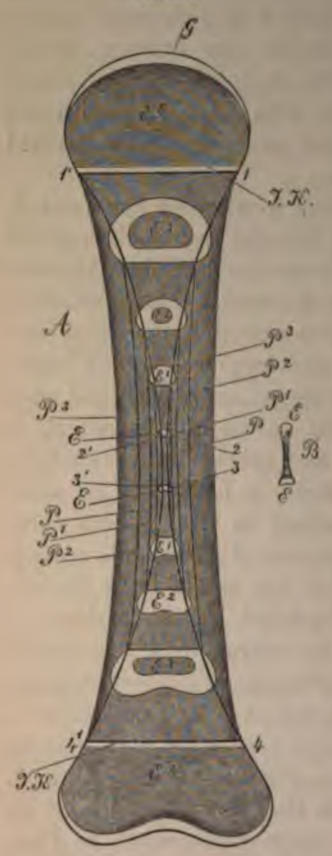


Diagram of the growth of a tubular bone. B. First rudiment in the diaphysis already ossified with cartilaginous epiphyses. A. The same bone with four additional stages of development, E^1PPE^1, $E^2P^1P^1E^2$, $E^3P^2P^2E^3$, $E^4P^3P^3E^4$. $P P^1 P^2 P^3$ periosteal layers of these four bones. The space between 1, 2, 3, 4, and 1′, 2′, 3′, 4′, indicates parts which in the largest bone have originated from cartilage. E^1E^1. Cartilaginous epiphyses of the second bone. E^2E^2. Epiphyses of the third bone with bone-nuclei. E^3E^3, E^4E^4. Epiphyses of the fourth and fifth bones with larger epiphysal nuclei. G. Articular cartilage. I.K. Interstitial cartilage between the bony epiphyses and diaphyses.

layers, of which only the latest remain more in their original form as the compact substance of these bones.

As is sufficiently apparent from what has been said, the *Haversian canals* arise not like the medullary spaces of the primary osseous substance, formed from ossified cartilage by a solution of existing tissue, but are *cavities which have been left from the commencement in the periosteal layers.* They are, at an early period, of relatively great size, and their lamellar systems are likewise developed without the co-operation of cartilage. These lamellæ are nothing but successive deposits from the soft substance in the canals, which, as was already mentioned, entirely agrees in its fibres and cells with the sub-periosteal ossific blastema, and is, so to speak, only the unossified remains of it. These points may be easily observed in young bones, in which the periosteal layers, before they have been opened up by partial resolution, become more and more compact by means of these new secondary lamellæ; but also in later periods, a more or less ossified blastema (always without calcareous granules) may very frequently be perceived upon the walls of the canals in question. Whilst the vascular canals thus generally become narrowed by secondary depositions, which, as in the periosteal deposits, appear stratified — because either the ossifying blastema is stratified or pauses ensue at definite periods in the deposition of the bone — some of them, on the other hand subsequently become widened by absorption, as, for example, the *canales nutritii,* the larger openings for the vessels upon the apophyses, many nerve-canals, etc., and, as already remarked, the compact substance is, in many places partially, in some even entirely absorbed.

The formation of bone upon the inner side of the periosteum, is a thing that has long been known, still it was hitherto the general opinion, that here also a thin layer of cartilage was concerned in it, until *Sharpey* and I proved the contrary. *Virchow* is of opinion that the ossific blastema arises from a luxuriant growth of the periosteum, and that its cells originate by a successive multiplication of the plasm-cells, whilst the fibrous matrix between them is simply an intercellular substance produced without the influence of cells from the fibrous substance of the periosteum. I, on the other hand, hold, that a layer of cells always exists upon the inner side of the periosteum, from which, by continual growth and multiplication, partly the ossifying cells proceed, partly others, which are metamorphosed with the fibrous matrix of the ossifying blastema.

The deposition from the periosteum, exhibits a certain contrast to the osseous substance which is developed from cartilage. The former principally forms the compact crust of the cartilaginously pre-formed bones, and is characterised by the presence of Haversian canals and their lamellar systems, whilst the latter produces the spongy substance and contains no vascular canals.

Still it is not to be forgotten, that all the periosteal layers are at first, to a certain degree, of a spongy texture, and, in all these bones, invariably contribute, and indeed frequently very essentially, to the formation of the spongy substance; further, that in the cellular substance also, which arises from cartilage, in the apophyses for example, secondary deposits, similar to those of the Haversian canals, and of the spongy substance derived from sub-periosteal deposition, occur to great an extent. The chemical and morphological relations of the matrix of the two osseous tissues in question, are not yet made out. On the other hand, the lacunæ of both kinds present not the slightest distinction; but it must be kept in mind, that, as has been shown in former sections, many of the bone-cells of the epiphyses, etc., seem to be formed in secondary depositions, and do not originate from the cartilage-cells themselves.

§ 105. *Bones not primarily cartilaginous* were, in man, till recently, only known to occur in the skull, but, according to *Bruch*, the clavicle belongs to this division (compare the remarks of H. Müller in *Zeitsch. f. wiss. Zool.* vol. ix.). The cranial bones belonging to this section arise outside of the primordial cranium between it and the muscular system, accordingly within the structures forming the vertebral system. When the skull first makes its appearance as a membranous and cartilaginous capsule, they are entirely absent, and only arise after the primordial cranium, from a secondary blastema. From this circumstance, and to distinguish them from the primary bones whose formative material is present at an earlier period, they are termed *secondary bones*, or also, because they are in contact in most places with parts of the primordial skull, *covering bones*. The following parts belong to the secondary bones: the upper half of the flat portion of the occipital bone, the parietal and frontal bones, the squamous portion of the temporals and tympanic ring, the nasal, lacrymal, malar and palate bones, the upper and lower maxillary, *vomer*, and, as it appears, the inner lamella of the pterygoid process, and the *cornua sphenoidalia*. The blastema of these bones, which, different from that of the primary bones, is successively developed into a membranous basis only when ossification takes place, and is not previously present in large quantity, presents essentially the same relations as that of the sub-periosteal depositions, and ossifies exactly in the same manner.

The opinion that certain cranial bones of man and mammalia are not developed from cartilage, is by no means new, still *Rathke*, *Reichert*, *Jacobson* and I were the first to establish the morphology of them; and *Sharpey* and I the histology of them. Nevertheless, there is by no means a general coincidence of opinion on the subject. With reference to the histology, I must refer the reader to the remarks made in my *Micr. Anat.*; with regard to the morphological aspect of the question, I will only remark, that the doctrine of the primordial cranium and the secondary bones is in a great measure independent of the question, whether the latter arise from cartilage or connective tissue. This is supported by the fact, that some bones proceed directly from the cartilaginous primordial cranium, whilst the others arise externally upon these, and are not pre-formed.

§ 106. All the cranial bones not primarily cartilaginous, first appear in the form of a very limited, elongated, or rounded *bone-nucleus*, consisting of a small quantity of fundamental substance, and some few lacunæ, and surrounded by a small amount of a soft blastema. The manner in which this nucleus arises has not hitherto been observed; still, from the method in which it is further developed, it may be deduced with certainty, that a short time previous to its appearance, a small lamella of the above-described soft blastema is formed in its place, which then, by the deposition of salts and the metamorphoses of its cells, ossifies from one point outwards. If an ossifying nucleus, for instance in the parietal bone, be once commenced, it advances in such a manner that, whilst the membranous blastema grows horizontally, a delicate layer of reticulating osseous trabeculæ soon arises, which sends out fine rays into the still unossified blastema (fig. 88). If it be examined more narrowly, it is found that the individual spicules of bone in the membranous blastema have arisen by the ossification of its elements, and have, as it were, consumed it in the places which they occupy, remains of it being left in their interstices; further, that the formation of the osseous elements takes place *entirely in the same manner as in the sub-periosteal deposits*, the rays of bone when traced to their growing-points

Fig. 88.

Parietal bone of a fœtus 14 weeks old. Magnified 18 times.

becoming softer, paler, and poorer in salts, and their cells resembling more and more the soft formative-cells, till at last, without any line of demarcation they are lost in the soft blastema. In these bones, there exists at first, only a horizontal growth; the rays, as they further extend and become connected by cross branches, continually adding to the size of the original network, but soon a *thickening* of the primitive lamella takes place by the deposition of layers both internally and externally, whilst at the same time the bone becomes more compact, and the more so the older it is. The thickening is due to the periosteum, which is found upon the surface of the secondary bones a short time after their appearance, and is developed either from their original blastema or from the neighbouring parts (perichondrium of the primordial skull, muscular and tendinous coverings). The osseous deposition proceeds exactly as in the sub-periosteal layers of the cartilaginously pre-formed bones, that is, a soft blastema is deposited upon the inner side of the periosteum, and gradually ossifies from the bone outwards, without ever having been cartilaginous (fig. 89). In this manner there is now formed, *particularly upon the outer, but also upon the inner side* of the primary osseous table, and proceeding from it, a succession of new lamellæ, and the young bone becomes thicker and thicker. All these new lamellæ are, like the earliest, at first reticulated; and then rounded or elongated, variously sized interspaces communicate with those of the already existing and the subsequent lamellæ, so that the osseous nuclei of the secondary bones, like the sub-periosteal layers, are from the first, penetrated by a network of canals, which, as in these, soon present the appearance of Haversian canals. At first, filled only by soft blastema, the remains of the formative material of the different layers, these spaces soon become narrowed by the advancing ossification in them, which partly crosses them in the form of bridges, as in the osseous rays of the borders, partly appears as

Fig. 89.

From the inner surface of a parietal bone of a new-born infant, magnified 300 times. *a*. Bone with lacunæ, still pale and soft. *b*. Border of the same. *c*. Ossifying blastema with its fibres and cells.

depositions upon their walls. Finally, some become thus closed, others are converted into true vascular canals, their contents developing vessels from the primitive formative cells, which now appear as marrow-cells; these vessels then communicate with those of the periosteum. When such a bone has thus far advanced in its development, the subsequent changes are easily understood. By means of the blastema, which is continually formed at its borders and surfaces, it continues to grow horizontally and in thickness, until it has attained its typical form and size, and in its interior, by solution of its compact substance, spongy substance (or even larger cavities) is subsequently formed; so that, like a bone which has been developed from cartilage and periosteal deposition, it finally contains, externally, compact substance with Haversian canals, and internally medullary spaces, but with distinct secondary deposits.

In concluding this account of the development of the bones, I may annex some remarks as to the periods of time in which the various stages are gone through. *Valentin* saw the cartilaginous basis of the ribs in a human embryo six lines long. From the sixth to the seventh week, that of the cranium can be distinctly recognised, also that of the vertebræ and of the suspensory zones of the limbs; that of the limbs themselves, at a somewhat later period (from the eighth to the ninth week). The ossification begins in the second month, first in the clavicle and lower jaw (fifth to the seventh week), then in the vertebræ, humerus, femur, the ribs and the cartilaginous part of the flat portion of the occipital. At the end of the second and commencement of the third month, the frontal bone, the scapula, the bones of the fore-arm and leg and upper jaw make their appearance. In the third month, the remaining cranial bones, with but few exceptions, begin to ossify, also the metatarsus and metacarpus and the phalanges; in the fourth month, the iliac bones and ossicles of the ear; in the fourth or fifth, the ethmoid, conchæ, sternum, pubis and ischium; from the sixth to the seventh month, the calcaneum and astragalus; in the eighth month, the hyoid bone. At birth, the epiphyses of all cylindrical bones, occasionally with the exception of those of the femur and tibia which are directed towards each other; further, all the bones of the carpus, the five smaller ones of the tarsus, the patella, sesamoid bones, and the last pieces of the coccyx are still unossified. From the time of birth to the fourth year, osseous nuclei make their appearance also in these parts, but in the pisiform bone not until the twelfth year. The junction of most of the epiphyses and processes with the diaphyses, takes place partly at the time of puberty, partly towards the end of the period of growth.

§ 107. The *vital phenomena* exhibited in the *fully mature bones* are not, during the vigorous period of life, accompanied with any notable or energetic morphological changes. It is true, that some of the processes formerly considered, still extend into this period — as the enlargement of the sinuses of the cranial bones, the widening or deepening of the muscular and tendinous impressions, and of the furrows of the vessels, etc.; but we never find any extensive new formation of bone under the periosteum or in the Haversian canals, and an absorption on a considerable scale going hand-in-hand with it. It was, indeed, believed formerly, that the colouring of the bones of the adult by the red colouring matter of madder, proves that depositions of osseous substance occur also at this period, because it was assumed, that only the newly forming osseous tissue became coloured; but since it has been shown, that fully developed bones are rendered red by madder, and that coloured bones of the adult do not become decolorised (*Brullé* and *Huguény*), the above-mentioned view can no longer be maintained. Whether in the fully developed bone a change, if not of the structural elements, at least of the atoms occurs, the former remaining the same, is another question, for the solving of which, hovever, the microscope furnishes no data. So much is certain, that the organisation of the bones is of such a kind, that notwithstanding their rigid nature, they come on all all sides, and most intimately in contact with the nutrient plasma of the blood. Everywhere, in fact, where the osseous substance is in connection with vessels, therefore, on the outer surface, upon the walls of medullary cavities and spaces, and upon those of the Haversian canals, there exist millions of fine openings crowded closely together. These conduct the blood-plasma by means of the canaliculi, into the bone-cells lying nearest to the above-mentioned surfaces, from which it is then conveyed by other canaliculi to more remote lacunæ, and at length to the outermost layers of the Haversian lamellæ and the layers of the great lamellar systems furthest removed from the vessels. When the immense number of the canaliculi and their numerous anastomoses are considered, it must be confessed, that in no tissue of the human body is better provision made for the distribution of the blood-plasma, but, indeed, in almost no tissue is the supply of fluid to the finest particles more necessary than here. There cannot be a doubt that the fluids, which this 'plasmatic vascular system' (*Lessing*) of the bones — which according to our present views, must be regarded as a *network of stellate cells* — receives from the blood-vessels, modified by the vital processes in the nucleated cells of the lacunæ, are indispensably necessary for the maintenance of the bones, for we see that when the vascular supply of a bone is cut off or impeded by the destruction of the periosteum or of the marrow, by the tying of the vessels of a limb, by obliteration of the periosteal vessels by pressure from without (aneurism, morbid growths), a necrosis of the parts concerned is the sure consequence. This, according to *Virchow*, frequently affects only the substance within the province of one or some few cells; nevertheless, the active collateral circulation (see above) is scarcely ever able to prevent it. On the other hand, we are not as yet able to say how the plasma of the bones circulates; for a movement of it from one set of vessels to another (probably from the more arterial through several lamellæ to the venous) must, doubtless be assumed; nor do we know in what actual changes the nutrition of the osseous tissue consists; and this more especially, because the chemical investigation of the process, and particularly of the organic products of the decomposition of bone is still very defective.

That the tissue of the bones is in a state of continual, and, indeed, very energetic change, is evinced not only by their various diseased conditions, but by the alterations they undergo in old age. At this period, extensive absorption of bone takes place, as well externally as internally; an example of the former is furnished by the alveolar processes of the jaw, which are wholly removed; of the latter by the increased porosity and brittleness of every description of bones, as the cylindrical bones, and those of the skull, by the enlargement of vascular openings (vertebræ, apophyses) and by the greater roughness of the surfaces of bones. To this senile atrophy of the bones a consecutive new formation of bone in the interior may be super-added, a so-called *sclerosis*, as in the flat cranial bones, by which means, in direct opposition to the other phenomena of senile bones, the diploë disappears, its spaces becoming filled with new osseous substance, the venous spaces and emissories being obliterated, and the entire bone becoming heavier.

From the vascularity of the bones, and their active elementary changes, it cannot be surprising that they are so richly provided with *nerves*. Of these, the *main function* is, in my opinion, to regulate the conditions of the vascular system. This end they may fulfil by conveying to the spinal cord or central organ, through means of their afferent fibres, impressions depending on the condition of the vessels, the quantity of nutrient fluid and the change of material in the bones, and conducting, by their efferent fibres, the reactive influence of the cord to the blood-vessels, which are evidently furnished with contractile coats. These nerves do not habitually give us distinct conscious sensations, but, in pathological conditions, they are capable of causing pain.

Pathological Conditions of the Bones.—Fractures, even in circumstances not the most favourable, readily heal by the formation of true osseous substance, which, in the cylindrical bones of animals, is preceded by the formation of true cartilage, but not invariably so in man. In spongy bones, in fractures within an articular capsule, and in otherwise unfavourable circumstances, the breach often heals by means of a fibrous callus only, and a kind of joint may be formed between the broken surfaces. After losses of substance, the osseous tissue is readily *regenerated*, and it is especially the periosteum which here plays a great part, as in the growth of the bones in thickness; this it effects, of course, by means of the exudation furnished by its vessels. In animals, entire bones of the extremities, as well as the ribs, may be regenerated when the periosteum is spared, as shown by many preparations in *Heine's* collection in the Würzburg Museum; but even after complete excision of the periosteum, a rudiment of bone is reproduced (*Heine*). In man, there are a good many examples known of the reproduction of entire bones, as of the lower jaw, ribs, and scapula (*Chopart*); and cases of partial reproduction, comprehending large portions of bone, are very numerous. It is more especially the diaphyses which are thus readily restored, no matter in what way they have been destroyed; more rarely, the spongy bones or spongy parts of bones, and the cranial bones; still, in the latter, the deficiencies after the operation of trepanning become, in many cases, occupied by separate osseous pieces, instead of a mere fibrous membrane, or are even completely filled up with bone; nay, pieces cut out with the trephine may be reunited, and the same has been observed to happen with pieces which have been partly hacked off (*Pauli*). *Hypertrophy* of the bones occurs in the most various forms, all of which may be reduced to two principal, viz.: 1, deposition upon the exterior, or external *hyperostosis*, which is chiefly formed from the periosteum; 2, deposition in the interior, *sclerosis*, or filling up of the medullary spaces, or Haversian canals, with new bone. These two forms occur either isolated or combined: the former occurs in inflammation of the periosteum alone, and in company with cancer, arthritis, syphilis, etc. the latter, consecutively in rachitis, osteomalacia, and syphilis, also in old age. With reference to the microscopical conditions, *Virchow* has the merit of having first demonstrated with distinctness, that in many cases of pathological formation of bone, this is effected by the ossification of connective tissue without the previous formation of cartilage. The new-formed osseous tissue is sometimes like the normal, sometimes firmer, with small vascular spaces and large irregular lacunæ. *Atrophy* of the bones shows itself in disappearances of the tissue in all its parts, in consequence of chronic diseases, paralysis, anchylosis, or as *rarefaction* of the osseous tissue analogous to *atrophia senilis*, in syphilis, lepra, mercurial cachexy, paralysis, etc. Death of the bones, *necrosis*, is observed in destruction of the periosteum, inflammation of the latter, and of the bone, etc., generally, accompanied with an excessive growth of the parts still healthy. Peculiar derangements of nutrition occasion *osteomalacia* and *rachitis*; yet, in the former, the microscopical investigation has afforded nothing worthy of being mentioned here. The latter has been narrowly investigated by myself and *H. Meyer*, and especially by *Virchow*, and presents some conditions which are worthy of being here considered. In the disproportionately large epiphysal cartilages, 1. the layer of the ossifying cartilage-cells (the cells arranged in rows) measures 2‴ to 5‴, instead of ½‴; 2. the border of ossification is dentated, the cartilage and the bone variously locking into one another; 3. in *well-marked* rachitic bones, the granular deposition of calcareous granules at the border of ossification is absent, and the cartilage-capsules are almost invariably transformed into bone-capsules somewhat before ossification of the matrix, and likewise without the formation of calcareous granules. It is on this account that the formation of the bone-capsules is nowhere more beautifully seen than in this case (see above). Upon the diaphyses the layer of the ossific blastema is much thicker, ossifies, likewise, very slowly, and presents a partial formation of cartilage.

Accidental formations of cartilage and bone are very frequent. The former tissue, notwithstanding that it is not regenerated, and that wounds of it heal only by means of fibrous tissue, or, more rarely, by osseous tissue (ribs), presents itself abnormally in very many organs (bones, mammary and parotid glands, testicles, lungs, skin), as the so-called enchondroma, and as a new covering upon the osseous growths at the border of worn-down articular extremities (*Ecker*). Accidental formation of bone appears in ossification of permanent cartilages (ribs, larynx, epiglottis [very rarely]), of tendons, upon the dura mater and arachnoid, in the eye, ovary, in fibrous membranes (*membrana obturatoria*), in enchondroma, fibroid tumours and cancers, and in the lungs (*Mohr's* cyst containing hairs). In these cases, also, the osseous substance is not essentially different from the normal, and arises, sometimes from a cartilaginous, sometimes, and, indeed, more frequently, from a soft blastema.

For the investigation of the bones, well-polished sections, which may be easily made, are of especial service. The investigation of decalcified bone also well repays the trouble bestowed upon it. This may be obtained by macerating a bone in cold diluted hydrochloric acid (1 part acid, 10 to 20 parts water), till no precipitate is produced by ammonia in the fluid, which should be frequently changed. With small pieces of bones, maceration for a few hours is sufficient; but for entire bones, several days are required. Sections of decalcified bone so prepared are to be made in all directions with a sharp knife, and may be used especially for the study of the Haversian canals and lamellæ; the latter can also be stripped off from the surface. The bone-cells, also, are still visible; their processes appear as fine striæ, and their nuclei come into view without further preparation, but especially after treatment with caustic potass, or after long boiling in water. After long maceration in hydrochloric acid, or after long boiling in a sand bath or a Papin's digester (*Hoppe*), the bone-cells themselves are obtained isolated as stellate bodies with delicate walls. The natural conditions of the lacunæ may be readily seen in thin sections of perfectly fresh bones, or in thin bone-lamellæ, as, for example, in many parts of the facial bones. In fresh bones, the vessels may be studied with the microscope, as they are naturally injected with blood. In this way the wished-for object is much more readily obtained than by artificial injections, which often fail, and in which, in order to permit of more close investigation, the bones must be subsequently decalcified in hydrochloric acid, and preserved in oil of turpentine. The nerves are found with the naked eye upon the nutrient arteries of the large cylindrical bones, and on smaller vessels with the aid of the microscope; those of the periosteum are to be studied after the tissue has been rendered transparent by caustic soda or acetic acid. For the study of the cartilage, the costal and articular cartilages are best adapted; in these, the cartilage-capsules partly present themselves to view without further treatment, partly after addition of acetic acid and caustic soda, which clears up the matrix. By boiling and maceration, the cartilage-capsules are readily isolated, and they naturally so occur in the yellow cartilages, especially in the large mammalia. The development of the bones may be investigated in a cylindrical bone and in a parietal bone, the formation of the lacunæ in rachitic bones, and upon the osseous surfaces of the symphyses and synchondroses.

Literature.—In addition to the works cited in § 5 and § 10, the following may be consulted:—VÖTSCH, *Die Heilung der Knochenbrüche, per primam Intentionem.* Heidelberg, 1847. KÖLLIKER, *Ueber Verknöcherung bei Rachitis,* in *Mitth. der Zürch. nat. Gesellsch.* 1847, p. 93. ROKITANSKY, in *Der Zeitschrift d. Wiener Aertze,* 1848, p. 1. A. KRUKENBERG, in MÜLL. *Arch.*, 1849, p. 403. H. MEYER, in MÜLL. *Arch.*, 1849, p. 292. VIRCHOW, in *Verhandl. der Wurzb. Phys. Med. Ges.*, Bd. i. No. 13. ROBIN, in *Mém. de la Société de Biolog.*, 1850, p. 179. J. TOMES and CAMPBELL DE MORGAN, *Obs. on the Struct. and Developm. of Bone,* in *Phil. Transact.*, 1853, i., p. 109. BRANDT, *Disquis. de ossific. Processu.* Dorp., 1852, Diss. BRUCH, *Beiträge zur Entwickelung des Knochensystems,* in *Denkschr. d. Schweiz. Nat. Gesellsch.*, xii. VIRCHOW, *Das normale Wachsthum und die rachitische Störung derselben,* in *s. Arch.*, iv., p. 409. H. MEYER, *Beitrag z. Lehre von den Knochenkrankheiten,* in *Zeitschr. f. rat. Med.*, iii, 1853, p. 143.

OF THE NERVOUS SYSTEM.

§ 108. The nervous system, regarded from an anatomical point of view, is a completely connected whole, in which two principal masses may be distinguished, the *spinal cord* and *brain*, and numerous cords proceeding from them to almost all parts of the body, the *nerves*. The two former, constituting the *central nervous system*, are not only to be regarded, from an anatomical point of view, as giving origin to the nerves, but also, physiologically, as excitors of movement, and as the seat of sensations and psychical actions; whilst to the latter, or the *peripheral nervous system*, a more subordinate office is ascribed, that of serving as intermediate or connecting parts in the production of sensation and motion.

This manner of viewing the Nervous System is, however, only partially correct, because, 1st, in the so-called central organs very many subordinate parts, as in the nerves, occur; and, 2nd, the peripheral nervous system possesses, in the so-called ganglia or nervous knots, likewise, physiological and anatomical central organs. The old classification, also, of the nervous system into *animal and vegetative* is no longer tenable when compared with recent observations, and the latter, or the *sympathetic* or *ganglionic nervous system*, is to be regarded only as a part of the peripheral nervous system, although peculiar in form.

Elements of the Nervous System.

§ 109. The *nerve-tubes* or *nerve-fibres* (fig. 90), also called *primitive tubules*, or *primitive fibres* of the nerves, are soft, fine, cylindrical fibrils, of 0·0005‴ to 0·01‴ in diameter, which constitute the main mass of the nerves and of the white substance of the central organs, but still are not wanting in most parts of the gray substance of the latter, and in the ganglia. When examined fresh, and by transmitted light, they are crystalline and transparent, with simple dark contours; by reflected light, shining and opalescent, like fat, for the most part white, and with no outward indication that they are composed of different constituents; still by various methods it is readily shown, that they consist of three entirely different structures, viz., a delicate envelope, a viscid fluid, and a soft but elastic fibre situate in the centre.

Fig. 90.

Nerve-fibres, magnified 350 times. 1. Of the dog and rabbit, in the natural condition; *a*. fine; *b*. middling thick; *c*. thick fibre, from the peripheral nerves. 2. Of the frog, with the addition of serum; *a*. drop forced out by pressure; *b*. axis cylinder in the same, continuing into the tube. 3. Of the fresh spinal cord of man, with the addition of serum; *a*. investment; *b*. medullary sheath, with double contours; *c*. axis cylinder. 4. Double contoured fibre of the human fourth ventricle, the axis cylinder (*a*) projecting and visible in the fibre. 5. Two isolated axis cylinders from the cord, the one undulated, the other unequally thick, with adherent medulla.

The *envelope* or *sheath* of the nerve-tubes (limiting membrane, *Valentin*), is an extremely delicate, yielding but elastic, homogeneous, and transparent membrane, which is invisible in perfectly unaltered nerve-fibres, except in a few places, but comes readily into view on the employment of proper re-agents, at least in the thicker fibres of the nerves and central organs, and, in its chemical characters, agrees in all essential points with the sarcolemma of the muscular fibres. This envelope has not hitherto been demonstrated upon the finest fibrils of the peripheral and central nervous system, and, accordingly, it is still uncertain whether these fibres possess sheaths or not.

Within the homogeneous sheath lies the *nerve-medulla* (medullary sheath, *Rosenthal* and *Purkinje*; white substance, *Schwann*) (figs. 90, 3, *b*), in the form of a cylindrical tube, closely and accurately surrounding the central fibres. It is, in the fresh nerve-fibre, perfectly homogeneous, viscid like a thick oil, transparent and clear, or white and shining, according to the light by which it may be viewed, and evidently causes the peculiar lustre of the nerves. Under the influence of cold, of water, most acids, and many other re-agents, the nerve-medulla is quickly and very constantly altered; this alteration is principally due to a coagulation, which proceeds from without inwards, and affects sometimes the whole medulla, sometimes only its outermost layers. In the latter case, the nerve-tubes appear *with double contours* (figs. 90, 91), or with medullary sheath coagulated to a more or less extent externally, but still fluid internally; in the former, the fibres have apparently quite grumous and dark contents (fig. 91). The coagulated nerve-medulla rarely appears homogeneous, but mostly grumous, granular, as if composed of irregular masses of various sizes, and, on the addition of acetic acid, frequently as if formed of small isolated or reticularly united rods. By pressure, also, the nerve-medulla alters very readily. It either flows out at the extremities of the tubes,

Fig. 91.

Human nerve-tubes, magnified 350 times. Three of them are fine, one of which is varicose, one of middling thickness and with a simple contour, and three thick, two of which are double contoured and one with grumous contents.

or out of varicose and ruptured parts of the sheath, and forms larger and smaller drops of all possible forms, regularly spherical, clavate, fusiform, cylindrical, filiform, or of the most odd shapes, which drops, like the nerve-fibres, may be coagulated only upon the surface or throughout; and, accordingly, like them, also, appear double contoured, or partially or completely grumous. But while within the tube, also, the medullary sheath alters, being accumulated at certain places in larger proportion, instead of forming a cylinder of uniform thickness. It is in this manner that the well known *varicose nerve-tubes* arise (fig. 91), in which the medulla presents sometimes beautiful moniliform swellings, sometimes irregularly distributed nodosities of various size, or even complete interruptions at some places. All these forms, in which the sheath may or may not take part, but in which the central fibre is not concerned, arise artificially, and are especially liable to occur in the finer fibres, and those with more delicate sheaths, such as are found in the central organs.

The *central fibre* of the nerve-tubes (primitive band, *Remak*; cylinder axis, *Purkinje*) (figs. 90, 2, 3, 4, 5), is a cylindrical or slightly flattened fibre, which, in unaltered nerves, is as little recognisable as the sheath, as it is completely surrounded by the medulla, and refracts the light in the same degree as this; but when the nerve-tube is torn through, or is treated with various re-agents, the axial fibre readily comes into view, partly in the interior of the tube, partly denuded, and is a constant structure. In the natural condition, it is pale, mostly homogeneous, more rarely finely granular or striated, bounded by straight, or occasionally irregular pale contours, and usually of equal thickness throughout; it is especially distinguished from the nerve-medulla by the circumstance, that although soft and flexible, it is not fluid and viscid, but firm and elastic, somewhat like coagulated albumen, with which it appears, for the most part, also, to agree in its chemical characters.

This so-called *axis-cylinder* is found in all nerve-fibres having nerve-medulla, also in the finest, everywhere presents the same characters, and equals in thickness nearly one-half or one-third of the diameter of the nerve-fibre.

The nerve-tubes, in which the three structures now described can be distinguished, and which we shall designate as the *medullated* or *dark-bordered*, form the preponderating majority of those found in the body; but there are some other forms deserving a more particular notice. These are the nerve-tubes, in which there is no trace of a nerve-medulla, and which possess a nerve-sheath, with contents sometimes completely resembling the axial fibre of other tubes, sometimes softer and more granular. These *non-medullated* nerve-tubes are found, in the first place, as continuations of the other sort, where they are connected with nerve-cells; in the second place, as longer independent tubes, in the form of the so-called processes of the nerve-cells of authors; and, lastly, at the terminations of the dark-bordered nerves. They may again be divided into several sub-divisions, according as they possess nuclei or not, and according as their contents are more or less transparent, or more or less consistent. When it is considered that the dark-bordered fibres also vary very much in their delicacy or fineness of structure, and in their diameter, which varies between 0·0005‴ to 0·01‴ and upwards,—so that they may be classified into fine and coarse, delicate and firm,—it is readily seen that the nerve-tubes, notwithstanding their general tubular character, differ a good deal from each other in several respects.

The envelope or sheath of the nerve-tubes discovered by *Schwann* can, in man, as on the roots of certain cerebral and of the spinal nerves, be only rarely seen without the aid of re-agents; but it is readily demonstrated by boiling the nerves in absolute alcohol, or acetic acid, or caustic soda. The sheath is best seen, however, by the aid of fuming nitric acid, and the subsequent addition of caustic potass. In this case, the fat of the medullary sheath passes out of the tube in form of pale drops, the axis cylinder is dissolved, and the yellow-coloured sheath remains behind empty, wider, and with swollen walls of 0·0004‴ to 0·0008‴ in thickness. Whether the finest nerve-tubes, also, of the central organs and peripheral nerves (below 0·002‴) possess a structureless sheath, is still undetermined. Analogy with the coarser fibres speaks for the existence of such sheaths; but there are some facts known, which seem to prove that there exist *sheathless* medullated and non-medullated primitive nerve-fibres. I have already, in my *Microscopical Anatomy* (II. i. 396), remarked, that in the tadpole, according to my observations, several dark-bordered fibres are developed in one and the same structureless sheath, formed by the coalescence of the cell-membranes; and that something similar, at least, according to *R. Wagner's* drawings, takes place in the electric organ of the torpedo, in which cases, special coverings around each separate tube can scarcely be assumed to exist. Quite recently, also, STANNIUS (*Götting. Nachr.*, 1850) has found in the lamprey that the nerve-fibres of the central organs possess neither sheaths nor medulla, and are, so to speak, nothing but free axis-fibres. Now, although it must be admitted, that the impossibility of demonstrating the sheaths does not by any means prove their non-existence, still the above-mentioned facts are deserving of attention; and we must, on this question, for the present, refrain from drawing conclusions from analogy. Upon the inner side of the sheath, between it and the medulla, there are, in many nerve-fibres, perhaps in all the peripheral nerves, *nuclei (Schiff)*, which correspond to those seen in the embryo, and also in the higher animals (see below), and especially in fish (in the electric organ, for example).

In order to see the *medullary sheath*, or *nerve-medulla*, in its normal condition, a nerve of a newly-killed animal must be quickly brought under the microscope without adding anything; in which case single fibres are always seen entirely unaltered, although they are very quickly altered by the drying of the nerve. Besides, I would recommend the observation of the nerves in the transparent parts of living or newly-killed animals (nictitating membrane, mucous membrane of the frog, the tail of the tadpole, etc.), and their examination upon warmed plates of glass (*Stark*), and after treatment with chromic acid, which maintains them, especially the cerebral nerves, often quite uninjured.

The *central fibre* of the nerve-tubes is, in human nerves, in the brain and spinal cord, as they are usually received for investigation, everywhere and with certainty recognisable on close examination, and, indeed, most easily in the central parts, where the absence of neurilemma and the delicateness of the nerve-sheaths less oppose the tearing of the tubes. Moreover, the central or axis-fibre may also be occasionally recognised in perfectly fresh nerves of animals. If a thin cutaneous nerve of a newly-killed frog be touched with a drop of concentrated or glacial acetic acid, while at the same time it is observed with a power magnifying 100 times, it is instantaneously seen, that whilst the nerve shortens, the pale, clear, axial fibre passes out at both the cut ends, together with large portions of the medullary sheath, which has become grumous. Alcohol and ether, especially when hot, display the axis-cylinder very beautifully. Besides the re-agents mentioned, chromic acid, corrosive sublimate, iodine, or iodine with hydriodic acid, may be used with advantage. Hydrochloric, sulphuric, and fuming nitric acid also bring the axis-cylinder, in certain cases, to view.

With reference to its chemical properties, the central fibre swells very considerably in concentrated acetic acid, dissolves, however, with difficulty, and, even after several minutes' boiling, although pale, is still unaltered. When boiled longer with acetic acid, it dissolves just as coagulated albumen does; on the other hand, the sheaths and some of the contents remain undissolved. Alkalies (potass, soda, ammonia), when cold, attack the axis-cylinder but slowly, still it becomes pale instantaneously in caustic soda, and swells up to 0·004‴, 0·005‴, or even 0·006‴ in diameter. Longer treatment in caustic soda dissolves it; and this takes place more rapidly with the aid of heat; as soon, in fact, as the fluid begins to boil. When treated with nitric acid and caustic potass, the axis-cylinder becomes yellow (xanthoproteic acid), and appears spirally contracted in the nerve-tube, which is also shortened, although in a slighter degree. On the other hand, sugar and concentrated sulphuric acid, which colour coagulated albumen red, do not colour the axis-cylinder, or at most, give it a yellowish or a slightly reddish tint. In water it is not altered, not even by boiling; but by that means it is readily isolated, and appears somewhat shrivelled; ether and alcohol, even when boiling, do not dissolve it, but cause it to shrink a little. The latter effect is produced also by corrosive sublimate, chromic acid, iodine, and carbonate of potass. Taking all these reactions together, it may, perhaps, be concluded with certainty, that the axis-cylinder is a coagulated protein compound, which, however, differs from fibrine, inasmuch as it does not dissolve in carbonate of potass and nitric acid, and offers much more resistance to acetic acid and caustic alkalies. It agrees with the substance which constitutes the muscular fibrils, in its elasticity and insolubility in carbonate of potass; but is distinguished from it by its insolubility in diluted hydrochloric acid, and its difficult solubility in acetic acid. The conclusion which may be drawn from these facts appears to me to be simply this, that the axis-cylinder is not an artificial product, but must be admitted to be an essential constituent of the living nerves.

Non-medullary nerve-fibres are found in many places. I reckon among them, 1. the pale fibres of the Pacinian bodies; 2. the nucleated pale fibres at the terminations of the olfactory nerves; 3. the perfectly transparent non-nucleated nerve-fibres in the cornea; 4. the pale, branched, and in part anastomosing nerve-terminations in the electric organs of *Torpedo* and *Rays*; 5. the similarly conditioned nerve-terminations in the skin of the mouse (*Kölliker*), and shrew-mouse (*Hessling*); 6. the pale processes of the nerve-cells of the central organs and ganglia, although they may not all pass into dark-bordered fibres; 7. the optic fibres in the retina and *Müller's fibres* in the latter, the nerve-terminations in the *cochlea*; 8. the nerve-fibres of invertebrata and of some fishes.

§ 110. The *nerve-cells* (nerve-corpuscles, *Valentin*) (fig. 92), are nucleated cells, which exist in large numbers in the grey or coloured

Fig. 92.

Nerve-cells, from the acoustic nerve; magnified 350 times. 1. Nerve-cell, with the origin of a fibre, from the anastomosis between the facial and auditory nerves, in the *meat. aud. int.* of the ox; *a.* membrane of the cell; *b* contents; *c.* pigment; *d.* nucleus; *e.* continuation of the sheath upon the nerve-fibre; *f.* nerve-fibre. 2. Two nerve-cells with fibres, from the *nerv. ampull. infer.* of the ox; *a.* sheath with nuclei; *b,* membrane of the cells; *d.* a fibre arising from the cell with nucleated sheath. I owe these drawings to the kindness of the Marquis Corti.

substance of the central organs, in the ganglia, occasionally, also, in the nervous trunks and the peripheral expansions of the nerves (retina, cochlea, vestibule). The nerve-cells possess, as outer covering, a delicate, structureless *membrane*, which can be readily demonstrated in the cells of the ganglia (the ganglion-cells, ganglion-corpuscles), but with great difficulty in those of the central organs; still even here, on the addition of re-agents, the membrane may be seen with tolerable distinctness in the larger cells, whilst in the smallest, just as in the finest nerve-tubes, such a membrane, although it perhaps exists, cannot be distinguished.

The contents of the nerve-cells are a soft, but viscid, elastic substance, which, apart from the cell-nucleus, consists of two parts: firstly, of a clear, homogeneous, slightly yellowish, or colourless matrix, which determines the physical properties of the contents of the nerve-cells, and is, for the most part, a protein compound; and, secondly, of fine granules of various kinds. In the colourless nerve-cells, the granules are distributed through the whole contents, and imbedded in the tenacious matrix in form of uniformly large, rounded, mostly very fine and pale, more rarely larger and dark, particles; whilst in the coloured cells, instead of these, there are found particles of a more or less yellowish brown, or black colour. These latter are mostly large, and usually lie close together at one part of the cell, in the neighbourhood of the nucleus; at other times, they almost completely fill the cell, and give it the appearance of a brown or black pigment-cell. In the midst of these contents the *cell-nucleus* is embedded, and is, for the most part, distinctly visible as a spherical vesicle, with well-defined walls, perfectly clear fluid contents, and one, or more rarely several, dark, large nucleoli, which occasionally contain a cavity in their interior.

The nerve-cells are very various in magnitude, being, like the fibres, of large, small, and medium size. The extremes for the cells are 0·002‴ to 0·003‴, and 0·05‴ to 0·06‴ in diameter. The nuclei, which mostly correspond to the cells, measure from 0·0015‴ to 0·008‴; the nucleoli, from 0·0005‴ to 0·003‴. The nerve-cells are further distinguished: 1. into *thin-walled* and *thick-walled*, of which the former are almost all found in the brain and spinal cord; and 2. into *independent cells* and *cells with pale processes*, which are either single, or in pairs, or several (uni-, bi-, multipolar cells), and ramify frequently; these processes are, in many places, continued into dark-bordered nerve-fibres, and are even to be regarded as non-medullated nerve-fibres.

Besides the nerve-cells, there exist in the grey substance of the higher central organs, as constant constituents, a *finely granular pale substance* which bears the greatest resemblance to the contents of the cells, and large local collections of *free cell-nuclei*. The retina, and, according to *Wagner* and *Robin*, the ganglia of plagiostomatous fishes, contain similar elements.

It is still undetermined whether or not the nerve-cells of the great central organs possess membranes. *Stannius* could not find them in the lamprey, and *R. Wagner* states the same to be true of the nerve-cells in the electric lobes of the torpedo. I believe I have seen a membrane in the large stellate corpuscles in the human spinal cord and cerebellum, and occasionally, also, in others; still I willingly admit, that in all the smaller cells, and the processes of the central cells in general, no covering can be perceived. This does not appear to me, however, a sufficient reason for denying its existence; and I believe that here, as in the case of the finest nerve-tubes, we must abstain, for the present, from giving a definite opinion.

Within the last year, *Stilling* has described a very complicated structure in the nerve-cells and nervous fibres, viz., anastomosing small tubuli occurring in great numbers in all parts of these elements. I for my part cannot lay great stress upon the assertion of this author, inasmuch as his observations have been made on chromic acid preparations, and because he gives no proof whatever that the pretended tubuli are really such.

Central Nervous System.

§ 111. *Spinal Marrow.*—The nervous elements in the spinal marrow are so distributed, that the external white substance is exclusively formed of nerve-tubes; the grey centre, with its processes or *cornua*, on the other hand, of nerve-tubes and nerve-cells, in almost equal proportion.

The *white substance* of the spinal marrow may, for convenience of description, be divided in the customary manner into two halves, and each of these into three columns. The anterior columns are almost completely separated from each other by the anterior fissure which extends along the whole length of the cord, and into which a vascular process of the pia mater dips, but are still connected at the bottom of the fissure by the anterior or white commissure. They extend outwardly to the place of exit of the anterior roots, or to the *sulcus lateralis anterior*, but are here, however, inseparably connected with the lateral cords, which, in like manner, at the place of exit of the posterior roots, where the *sulcus lateralis posterior* is situate, pass into the posterior cords without any line of demarcation. These posterior cords apparently meet, it is true, in the posterior median line, inasmuch as the posterior fissure assumed by many does not exist in man, except in the lumbar enlargement and the upper cervical region; but they are so separated from each other, in the entire extent of the cord, by very numerous vessels and connective tissue, which, in the posterior median line, penetrate as far as the grey central part, that their elements do not, in most places, come in contact at all, and where this is the case, are only in juxtaposition, and never pass from one side to the other. The whole substance of the cord, accordingly, exhibits two halves, united only by the anterior white commissure, each of which may be divided more artificially into three columns, which fill up the depressions existing between the projections of the grey substance.

The *grey substance* possesses a middle ribbon-shaped portion and four laminæ, proceeding from it laterally, so that, when viewed in a transverse section, it forms a cross. The middle portion, or *grey commissure*, contains, in the fœtus, and, in most cases, also in the adult, a canal (*canalis spinalis*), with cylindrical epithelium, and, around this, a grey substance, the *central grey nucleus*, as it was termed by me, but which, with *Virchow*, I reckon the ependyma of the *canalis spinalis*, and will call *central ependymatic filament*. Before and behind this filament there are nerve-fibres running in the transverse direction, the grey or posterior commissure. Of the grey laminæ, also called horns (*cornua*), the anterior are shorter and thicker, uniformly grey, and composed of larger and smaller nerve-cells and delicate moderately-fine nerve-fibres; the posterior are longer and narrower, and, at their origin, constructed like the anterior, but mostly with smaller cells; at the free border, on the other hand, they are covered by a clearer layer, composed principally of small cells, *substantia gelatinosa* (*Rolando*). With regard to the roots of the spinal nerves, the anterior pass between the anterior and lateral columns direct to the anterior cornua; and the posterior, passing through the *substantia gelatinosa* into the posterior laminæ, are lost between the lateral and posterior columns.

With regard to the internal structure of the spinal marrow, there are to be distinguished in the *white substance*, 1, horizontal, and, 2, longitudinal fibres. The latter are found in all places with the exception of the anterior commissure, are, for the most part, unmixed with horizontal fibres, and run everywhere parallel to each other, without even forming plexuses or constituting fine bundles. These fibres, of 0·0012‴ to 0·0048‴ in thickness, decrease in number from above downwards, while, as will be afterwards shown, they successively pass into the grey substance, and present the general characters of central nerve-tubes. The *transverse fibres* are found, 1, in the parts of the lateral and posterior columns adjoining the cornua of the grey substance, the description of which will be given below when treating of that substance; 2, in the white commissure; and, 3, at the place of entrance of the roots of the nerves. The *white* or *anterior commissure* is only in part a commissure, in the usual acceptation of the term, inasmuch as it is formed, in part, by the deepest nerve-fibres of the anterior columns, which, whilst they bend inwards in an oblique direction, decussate in front of the grey commissure,—the bundles coming from the right anterior column spreading out horizontally in the left anterior horn of the grey substance, and those from the left column radiating into the right anterior horn. Other fibres of this commissure are real commissural filaments, and spread from it into the posterior grey horns, and towards the lateral and anterior columns. The anterior commissure, whose thickness is in a great measure proportionate to that of the motor roots, and whose breadth is dependent upon that of the spinal marrow, is, accordingly, in part a real *decussation of the anterior columns.*

Fig. 93.

Transverse section of human spinal cord, close to the third and fourth cervical nerves; magnified ten diameters (from *Stilling*) *f*. Posterior columns. *ii*. Gelatinous substance of the posterior horn. *k*. Posterior root. *l*. Supposed anterior roots. *a*. Anterior fissure. *e*. Posterior fissure. *b*. Gray commissure, in which a canal is contained, which, according to this writer, extends through the length of the cord. *g*. Anterior horn of gray matter containing caudate vesicles. *c*. Antero-lateral column (from *k* to *a*).

The roots of the spinal nerves (fig. 93), without associating at all with the longitudinal fibres, pass between them horizontally, or in a slightly ascending direction, from the *sulcus lateralis anterior* and *posterior*, in order to dip into the anterior and posterior grey laminæ, where we shall meet with them again. Their nerve-tubes possess, as they pass into the cord, all the characters of central fibres, and at first measure, in the sensitive roots, 0·004‴ to 0·006‴, in the motory up to 0·008‴, but visibly become narrower and narrower, so that finally the former pass into the grey substance with a diameter scarcely more than 0·0012‴ to 0·0028‴, the latter with a diameter generally not more than 0·004‴.

In the grey substance, the nerve-cells and the nerve-tubes are deserving of special consideration. The former occur in various forms; but all agree in the circumstance, that they invariably possess several processes, which finally, ramifying, run out into very fine pale fibrils, like the finest central fibres of the nerve-tubes. At the apex of the anterior horn especially, they are well-developed large nerve-cells, forming an inner and an outer group (fig. 93 *g*); they also occur in the other parts of the anterior horn, and also, although less numerously, in the posterior horn, in which, between the two enlargements, a part of them forms a very remarkable group, at the outer side of the apex of the posterior fasciculi (*Clarke's* posterior vesicular columns), but never in the substantia gelatinosa and the grey commissure. All these cells are 0·03‴ to 0·06‴ in size, fusiform or polygonal, frequently brown-pigmented, with nuclei of 0·005‴ to 0·008‴, and with 2 to 9, or even more, branched processes, which, at their origin, are frequently 0·004‴ to 0·005‴ thick, and can be followed for a distance of 0·1‴ to 0·24‴. These processes finally run out into fine fibrils, which are scarcely thicker than 0·0004‴, all lying in the grey substance. Besides these large multi-radiate cells, there occur in the grey substance, and also in the substantia gelatinosa, other very numerous but more isolated small cells between the nerve-tubes, the signification of which it is difficult to ascertain in the actual case. Some of them are evidently nerve-cells; others are no less certainly merely plasm-cells, such as occur in connective tissue, and belong to the stroma of that tissue, which is distributed

Fig. 94.

Large nerve-cells, with processes from the anterior horns of the human spinal cord, magnified 350 times.

throughout the entire extent of the spinal marrow, and supports the nervous elements.

The nerve-tubes of the grey substance are extremely numerous, constituting in every case the half, if not more, of it, and present the same characters as those of the white substance, except that they are, on an average, only of half the diameter, or less (down to 0·0008‴). Still, just as in the white substance and the entering nerve-roots, large fibres are also found here, especially in the anterior horns, but more isolated, and particularly towards the anterior roots. The investigation of the course of these nerve-fibres in the grey substance is one of the most difficult of microscopical tasks. If we here more especially consider those of the *nerve-roots*; it is seen, that the fibres of the anterior or *motory* roots, after they have passed into the *sulcus lateralis anterior*, and into the adjoining parts of the anterior and lateral columns, and have penetrated horizontally through the longitudinal fibres of these, extend further in the grey substance of the anterior horn chiefly in two directions. Some fasciculi proceed directly backwards and somewhat inwards in the innermost part of the anterior horns, bordering on the anterior columns. In this course, many of them pass through the inner group of large nerve-cells, without appearing to be connected with the processes of the cells, and, still running in the anterior horns, finally arrive at the lateral parts of the anterior commissure; they are then continued into the fibres of the latter, and, indeed, in such a manner, that the root-fibres of the right side pass into the left anterior columns, those of the left side into the right. In the white commissure, accordingly, a connection of the longitudinal fibres of the anterior columns, and of a part of the motor roots, conjoined with a total decussation, takes place.

Another part of the fibres of the motor roots, viz., the outer root-fibres entering the anterior horns, have not the slightest connection with the anterior columns. These fibres, which are generally distributed in bundles, or may even separate into individual fibres, and are, consequently, less readily observable, run partly directly backwards, partly in a curved manner outwards, but finally turn to the anterior half of the lateral columns, where they pass through the outer group of the large multi-radiate cells of the anterior horns, and then enter the lateral columns in a horizontal course. Now, these transverse fibres extend for a variable distance into the lateral columns (to nearly half or more outwards), then turn *upwards*, and pursue their course further as longitudinal fibres; in other words, a second part of the motor roots is in connection with the anterior half of the lateral column of the same side, and leaves the cord without ever having decussated.

Besides these fibres, there exist many others from the motory roots, which, after having entered the grey substance, spread out in this, especially in the direction of the posterior grey horns, and are lost in the inextricable network of fine nerve-fibres, which occurs in nearly every part of the grey substance.

All fibres of the motor roots become smaller and smaller from their entrance into the cord as far as the grey substance, to increase again when they join the longitudinal elements of the medulla, although they never regain their original diameter.

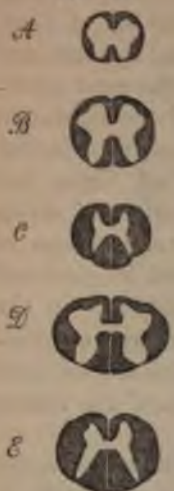
Besides the fibres of the motor roots, which, in the cord, are directly continued into the elements of the anterior and lateral columns, others, according to recent investigations, appear to exist, which stand in connection with the nerve-cells, and, accordingly, seem thus to take their origin in the spinal marrow itself.

The *posterior* nerve-roots (fig. 93. *k*) pass horizontally, or somewhat obliquely upwards, from the *sulcus lateralis posterior* through the longitudinal fibres of the region of conjunction of the lateral and posterior columns, and through the latter, in which they run generally in a beautifully arched manner, as far as the posterior horns. Here they separate into larger and smaller bundles (of 0·01‴ to 0·02‴), and each separately is continued directly and without entering into any direct connection with nerve-cells through the *substantia gelatinosa* into the *substantia grisea*. In the latter, they pursue different directions. One set of them bend in a curved manner, or nearly at a right angle, upwards and downwards (*Clarke*), run farther longitudinally in the most posterior part of the *substantia grisea*, close in front of the substantia gelatinosa, and seem partly to join the posterior and lateral columns in order to extend further as longitudinal fibres, but partly to enter again the grey substance in a horizontal direction. A second part of the sensitive roots penetrate always in bundles further forwards between the just mentioned longitudinal bundles in the grey substance itself, and are finally lost in the anterior horns, in the grey or posterior, and the anterior commissure. The grey commissure stands in connection with the sensitive roots, but its fibres also spread out in the direction of the lateral white columns and the anterior grey horns.

In the *substantia gelatinosa*, the fibres of the sensitive roots never measure more than 0·004‴; in the grey substance, 0·001‴ to 0·003‴; in the grey commissures, only 0·0008‴ to 0·0012‴; and in the posterior and lateral columns again, 0·0012 to 0.004‴. Several authors are of opinion, that certain of the fibres of the sensitive roots are also connected with the nerve-cells in the spinal marrow; still this point is not nearly so well ascertained as in the case of the anterior roots. Besides the fibres connected with the motory and sensitive nerves, there are seen in the grey substance a good many nerve-tubes, which cannot be directly traced to the roots, although they may possibly belong to them.

The *central canal*, which some authors, as *Stilling* and *Wagner*, regard as constant, seems to be sometimes obliterated in the adult. When it exists, it is well marked in the entire length of the cord with a width varying from 0·01‴ to 0·1‴, and of a rounded or triangular form. It lies in the midst of the central grey nucleus, which, with *Virchow*, I refer to the ependyma, and consider analogous to the thickenings of the ependyma of the brain. This substance is thickest in the lumbar enlargement, and presents a pyriform, scutiform, or heart-shaped figure on a transverse section. The cells embedded in it are, from their stellated form and branched processes, undoubtedly very similar to nerve-cells; they have, however, frequently as many as five nuclei, and must be ranked with the plasm-cells of the connective tissue. In chromic acid preparations, I have seen cilia upon the cylindrical epithelial cells of the central canal, which observation has been confirmed by *Stilling*.

Fig. 98.



Five transverse sections through a human spinal cord, hardened by chromic acid, to show the relative proportions of the gray and white substances, of natural size. A. From the conus medullaris. B. From the lumbar enlargement. C. From the dorsal part. D. From the cervical enlargement. E. From the superior cervical portion.

The *filum terminale* is traversed in its whole length by a continuation of the central canal of the marrow, and contains, in its upper part true dark bordered nervous fibres.

§ 112. *Probable course of the Nerve-fibres in the Spinal Cord.*—We have found that the motor and sensitive roots do not terminate in the grey substance of the cord at their point of attachment, as would appear at first sight, but that a part of them turn upwards, and accompany the longitudinal fibres of the white substance. The important question now is to know what becomes of these fibres, whether after a shorter or longer course they terminate in the cord, or whether they all ascend to the brain. As is well known, the majority of inquirers have been till quite lately of the latter opinion, which was based less upon direct observations, than upon the ground of probability, until *Volkmann*, in his justly celebrated article, '*Nervenphysiologie*,' WAGNER's *Handworterb. d. Physiol.*, vol. ii., shook it to its foundation, carrying the majority of physiologists with him. I have, however, shown, that *Volkmann's* arguments are not sufficient; and from this time a series of new investigations have been made, from which it appears to become more and more evident, that a part of the fibres of the spinal nerves come from the brain, whilst another arises or ends in the cord itself.

Whoever wishes to become acquainted with the particulars of *Volkmann's* statements and my refutation of them, may find them in my Microscopical Anatomy.

The more recent works of *Stilling*, *Clarke*, myself, *R. Wagner*, *Bidder* and his scholars, and *Schröder v. d. Kolk*, upon the spinal marrow, differ in many respects; and I may notice here some of the principal points. The principal difference consists in this: that *Bidder* and others assert, that *all* the fibres of the roots of the spinal nerves, as well as all the fibres of the white substance, are connected with the nerve-cells in the spinal marrow, whilst, according to me, many nerve-fibres proceed directly from the brain towards the periphery, and *vice versa*. Moreover, *Schröder von der Kolk* and *R. Wagner* assert, that the nerve-cells also anastomose by means of their processes, whilst it has not, in my opinion, been demonstrated that these processes, which I was the first to declare as a kind of nerve-fibres, have not also free terminations.

With reference to the course of the fibres in the cord, *Stilling* has advanced a hypothesis which holds a middle position between the one defended by me and that of *Volkmann*. *Stilling* is of opinion; 1, that all the fibres of the motor roots arise from the cells of the anterior horns; 2, that the majority of the fibres of the sensitive roots probably pass directly into the longitudinal fibres of the posterior columns; 3, that the remaining portion of the longitudinal fibres of the white substance, accordingly, the anterior and lateral columns, take their origin from the cells of the gray substance; 4, that the anterior commissure represents a connection of the two anterior horns; and, 5, that the gray substance contains no special fibres. *Wagner*, on his part, is inclined to hold, that first, all the nerve-cells of the cord anastomose with each other, and, secondly, that the greater part also of the fibres arise from the cells, yet the special descriptions of these relations, which he has given in his last work, differ very considerably from each other. As far as I am concerned, it appears to me in the first place as yet impossible to give an accurate exposition of the course of the fibres in the cord, and the following, accordingly, may be regarded only as an outline to be filled up by future researches. First of all, it appears certain, that part of the spinal nerves do not arise in the cord, but in the brain; and I am not disinclined to assume, that part of the sensitive fibres of the skin and of the outermost parts of the mucous membranes, as well as of the motory fibres of the voluntary muscles belong to this category. Secondly, I consider it as probable, that the fibres proceeding from the spinal marrow to the sympathetic and other parts, as vessels, cutaneous muscles, bones, etc., which are but remotely connected with conscious sensations and subservient to the involuntary movements, in as far as they do not come from spinal ganglia, arise in the spinal cord from the nerve-cells.* Thirdly and lastly, I think I am warranted in affirming the existence of anastomoses of the nerve-cells, although I do not assert that their processes may not also run out into free extremities, and, without entering into direct connection with the nerve-fibres, act upon the latter. Since, at any rate, all the elements of the nervous system

* A part of these fibres, also a part of the sensitive fibres of the skin, and of the motor elements of the voluntary muscles, may possibly take their origin in the spinal marrow, which fibres then would correspond to the excito-motory elements of *Marshall Hall*

are not continuously connected with each other — the unipolar cells, which undoubtedly exist in many places for example — there is certainly no necessity for assuming something of this kind in the case of the spinal cord, and by this means render the isolated conduction of the nervous influence in definite paths more inexplicable.

The most recent Dorpat dissertations give very interesting information on the spinal cord of birds, of fishes, and of frogs; still, as *Stilling* and I have recently shown (see *Z. f. Wiss. Zool.*, vol. ix.), they are in many respects inexact. At all events, we must be on our guard in applying these relations to the human cord without further investigation. In the lower vertebrata, the gray substance evidently contains connective tissue, and from this circumstance *Owsjannikow* supposes that it also occurs in man. This is, in fact, the case, inasmuch as I find throughout the whole gray substance, cells, which present the character of plasm-cells, and lie in a more homogeneous stroma. In the white substance besides, areolar tissue undoubtedly accompanies the vessels.

§ 113. The *Medulla Oblongata* and *Pons Varolii* belong to the most complicated parts of the central nervous system, and contain white and grey substance, intermingled in very various ways. Besides the well-known bundles of white substance, as the *pyramids, olivary bundles*, etc., whose description is given in every hand-book of Anatomy, it contains a peculiar system of horizontal fibres, which appear to me, in part, to pass from the *restiform bodies* and the peduncles of the cerebellum into the anterior part of the medulla oblongata (see *Stilling's* work and my *Micros. Anatomy*). All bundles of the white substance consist of parallel nerve-tubes of the same dimensions as those of the cord.

The *gray substance* is found collected in the *medulla oblongata*, especially at three places: 1. In the *olivary bodies* it forms the well-known folded lamina constituting a capsule, which is shut on all sides except the inner, and consists of smaller stellated nerve-cells, and fibres of the horizontal system traversing them. 2. In the *restiform bodies* the gray substance is not sharply defined, and occupies especially the *fasciculus lateralis*. It is a continuation of the posterior horns of the spinal cord, and even presents an indication of the *substantia gelatinosa*. 3. The *gray substance* at the bottom of the fourth ventricle, is a continuation of the anterior parts of the gray substance of the cord, and forms a tolerably thick layer extending from the *calamus scriptorius* to the *aquæductus Sylvii*. It contains numerous nerve-tubes in part of very considerable size, up to 0·006‴, or even 0·008‴, in part of the finer and finest kinds; besides these, nothing but multipolar nerve-cells from 0·006‴ up to 0·03‴ and more. The *ala cinerea* and *substantia ferruginea* possess the largest cells, and in the latter place the cells are pigmented and beautifully branched. The *pons Varolii* contains, besides the just-mentioned gray masses, which in part belong to it, numerous collections of gray substance in its interior, with smaller and larger multipolar cells, which are so irregularly imbedded between the white fibres, that they do not admit of a detailed description.

It is a difficult matter to ascertain the relations of the ten pairs of nerves, which come from the medulla oblongata, the *pons* and the cerebral peduncles. But few inquirers have endeavoured to solve this question by other than the usual means; that is to say, by following the fibres with the knife, which is not all-sufficient here. Among these exceptions are *E. Weber*, who employs preparations hardened in carbonate of potash, and *Stilling*, who uses alcohol-preparations. The results which I myself obtained by chromic-acid-preparations, which were mostly rendered transparent by caustic soda, agree in almost every respect with those of *Stilling*, to whom we are indebted for a very beautiful work on the *medulla oblongata* and the *pons*. The ten posterior cerebral nerves arise without exception, not from the columns or collections of fibres from which they pass out, but all penetrate more or less deeply into the central parts, and all, probably, become connected (some not till they have decussated, like the *trochlearis* and probably the *hypoglossus* and *accessorius*) with definite parts of the gray substance, which *Stilling* not inaptly calls *nerve-nuclei*. It is especially the floor of the fourth ventricle, and the aqueduct of Sylvius, which are concerned in these origins, seeing that all the nerves in question extend at least partially to them. For particulars, see *Stilling's* work and my *Micros. Anatomy*, ii. pp. 458—462.

§ 114. The *Cerebellum*, in the distribution of its elementary parts, presents rather simple relations, grey substance occurring only upon the surface of the convolutions, in the *nucleus dentatus*, and upon the roof of the fourth ventricle; all the rest consists of white substance. The latter is made up solely of parallel, probably unbranched, dark-bordered nerve-tubes, which possess all the characters of central tubes. As far as can be ascertained, they present almost everywhere essentially the same relations, and measure from 0·0012‴ to 0·004‴ in diameter, their mean diameter being 0·002‴. The grey substance exists, 1, very sparingly upon the roof of the fourth ventricle, above the *velum medullare inferius*, in the form of brown cells, of 0·02‴ to 0·03‴ in size, scattered in the white substance, and readily recognisable by a practised eye; 2, in the *nucleus dentatus*, whose greyish-red lamella contains a considerable number of yellowish pigmentated nerve-cells of medium size (0·008‴ to 0·016‴), furnished with from two to five processes, which are not directly connected with the numerous nerve-fibres passing between them from the white centre of the *nucleus dentatus* into the white substance of the hemispheres.

The relations of the grey substance upon the surface of the convolutions of the cerebellum are more complicated (see my *Microsc. Anat.*, tab. iv. fig. 4). That substance, as is well known, consists everywhere of an *inner rust-coloured* and an *outer grey layer*, which, except in the furrows, in which the inner layer is generally thicker, are nearly of equal thickness the one with the other, although their absolute thickness is not everywhere the same.

The *inner rust-coloured layer* contains nerve-fibres and large collections of free nuclei. The former come from the white substance, and pass directly from within into the rust-coloured layer, generally parallel to each other, although in all the convolutions on a transverse section the fibres spread out in a slight degree like a brush. In this layer, they likewise run from within outwards, as far as the grey layer, but break up into many, mostly fine bundles, which are variously interwoven with each other. In the meshes of these nerve-fibres are situated immense numbers of dark, round corpuscles, of 0·002‴ to 0·004‴, on an average 0·003‴, in size, which appear to be *free cell-nuclei*, and very frequently present a distinct nucleolus. The nerve-fibres, diminished to 0·0012‴ in diameter, pass out of the rust-coloured layer into the outer *grey layer*. The latter, although in outward appearance everywhere quite uniform, consists of two, but not sharply defined layers, of which the inner contains nerve-fibres and very beautiful large nerve-cells, the outer, on the other hand, presents only a finely-granular, pale, slightly yellowish substance, which, in general, is distributed throughout the whole grey layer, and small nerve-cells with delicate processes. Altogether different from these smaller elements, and, at the same time, very peculiar, are the *large* cells of the grey layer (fig. 96), discovered by *Purkinje*. These cells, of 0·016‴ to 0·03‴ in size, and of a round, pyriform, or ovoid shape, with finely granular, colourless contents, are found only in the innermost parts of the grey layer at the limit of the rust-coloured substance, in a single or double layer, and possess usually from 2 to 3 long, variously branched processes, of which one more delicate is directed inwards, the thicker outwards. The outer processes have at the root a thickness of 0·007‴ or 0·008‴,

Fig. 96.

Large cells of the grey layer of the cortical substance of the human cerebellum. Magnified 350 times.

and are there very finely granular in substance, or very delicately streaked; but, in their further course, they become more homogeneous, and, at the same time, ramify in the most varied and beautiful manner, so that at last each process ends in a large tuft of very fine fibrils, the finest of which are scarcely 0·0002‴ in diameter. A part of them penetrate more horizontally into the grey layer; most of them, however, proceed directly outwards, and extend into two-thirds or three-fourths of its thickness.

In the innermost part of the grey layer, between the large cells, there are also nerve-fibres which become progressively finer, and exchanging their dark contours for paler, diminish in thickness to 0·0006‴ and 0·0004‴; finally, running in a more straight direction and isolated, and becoming almost as pale as processes of nerve-cells, they are lost at the limit between the inner and middle third of the grey layer. All the *crura cerebelli* consist of parallel nerve-tubes.

§ 115. *Ganglia of the Cerebrum.*—All the three pairs of ganglia of the brain, *corpora quadrigemina, optic thalami,* and *corpora striata,* consist of large collections of grey substance and of nerve-fibres, of which the former are in part perfectly isolated (*corpus striatum*), in part connected with each other and with grey parts situate deeper (*thalami optici, corpora quadrigemina*); whilst the fibres connect the ganglia, on the one hand, with the cerebellum and medulla oblongata, and, on the other, with the hemispheres of the cerebrum.

The *corpus striatum* contains two large grey nuclei, the *nucleus caudatus*, situate anteriorly and superiorly, and the *nucleus lenticularis*, inferiorly and posteriorly, which, however, are connected anteriorly with each other, and form one mass; also the thin *nucleus tæniæformis* with the *amygdala*, to the outer side of the lenticular nucleus. The *corpus striatum* is principally connected with the base of the cerebral peduncle or the contination of the pyramid, which spreads out in it with numerous white fibres. The grey substance, as is almost everywhere the case, exhibits *nerve-cells* and fine *nerve-fibres*. The former, of 0·006‴ to 0·018‴ in size, are, in part, colourless; in part, as especially in the *nucleus caudatus* and third section of the *nucleus lenticularis*, pigmentated; they have two to five processes, and their number is proportionate to the depth of colour of the grey substance.

The nerve-fibres can, for the most part, be referred to the base of the cerebral peduncle. They are dark-bordered tubes, of 0·0012‴ to 0·005‴, mostly of 0·002‴ to 0·004‴ in size, which lying parallel to each other, penetrate in a straight direction into the first division of the lenticular nucleus, and the most anterior, thickest part of the caudate nucleus. If they be followed further in the lenticular nucleus, they are seen to form larger and smaller bundles, and then, decreasing somewhat in thickness (the most of them measure 0·0012‴ to 0·003‴), to pass in a straight direction through the less abundant grey substance of the two first divisions of it, in order, at last, to radiate in form of pencils into the outermost largest division, where they are lost to view. That is to say, white bundles of 0·04‴ to 0·14‴, with fibres from 0·0012‴ to 0·002‴, pass parallel to one another from the second division into the third, which bundles, slightly diverging and dividing into smaller ones, proceed further towards the outer border of the lenticular nucleus, and before they have reached it, disappear to the naked eye. If these fibres be followed microscopically in chromic acid preparations, it is found that the bundles proceed to near the outermost part of the lenticular nucleus, gradually, however, separate into smaller bundles and separate fibres, and become interwoven with one another in various ways. *That these fibres terminate here, and do not proceed farther into the white substance of the hemispheres, may be regarded as established,* since not a trace of their further progress is observable; and were they really continued farther, the fact could scarcely fail to be discovered on careful inspection. Withdrawn from view, it is doubtful, on the other hand, how they terminate. All I can say is, that the fibres of the nerve-bundles entering into the third division of the lenticular nucleus, as may be directly observed in many preparations, become gradually so fine that they measure only 0·0008‴ to 0·0006‴, or even 0·0004‴ in diameter, and appear almost quite pale, so that they are scarcely distinguished from the finer processes of the nerve-cells, with which, in fact, unless the whole appearance is deceptive, they may in reality be connected. All the fibres entering the *nucleus caudatus* present a corresponding arrangement with those just described. One part of them proceed directly from the base of the cerebral peduncle into the nucleus; the other, entering its thinner part, obviously come from the *nucleus lenticularis*, having previously passed through the two first divisions of the latter. Here, also, there is no transition of these fibres into the white substance of the hemispheres, but a separation of the bundles into networks of the finest, almost non-medullary fibres, and most probably a connection of the fibres with the cells.

Besides the above-described, and, unquestionably, very numerous nerve-fibres, which come from the cerebral peduncles and terminate in the *corpus striatum*, the nuclei of the latter contain a considerable number of others, of whose origin it is difficult, and, in some respects, impossible, to speak positively. I believe I can trace one set of these tubes to their origin. In the outermost part of the great nucleus of the *corpus striatum*, there is found in different sections a considerable number of bundles of tolerable size, but invisible to the naked eye, which are distinguished by their comparative thickness and the diameter of their tubes (from 0·0012‴ to 0·002‴), from the fibres of the cerebral peduncle, which are here very fine and split up into networks. It is easy to see that all these bundles come from the medullary substance of the hemispheres, and that they enter the *corpus striatum* after, as it appears, they have run for a certain distance at the border, and parallel to the surface of that body. Many of these fibres also simply extend from the medullary substance into the ganglia, and in this course decussate with the former fibres at a right angle. All these fibres, collected into bundles, penetrate into the grey substance of the *corpus striatum* and the third division of the lenticular nucleus, and then terminate, as I believe I have found, in narrow loops, without forming expansions or plexuses, or suffering further attenuation.

While it is comparatively easy to ascertain, at least in its principal features, the structure of the *corpora striata*, it is far otherwise with the *optic thalami* and *corpora quadrigemina*, and chiefly because the nerve-fibres are less disposed in bundles, but more isolated and most intimately mingled with the grey substance, and, consequently, cannot be followed for any great length. In this situation, however, the investigation of the grey substance is perfectly easy, and its elements, the nerve-cells, present nothing that is peculiar, except that, in the *optic thalami*, they are, for the most part, deeply coloured; those of the *corpora quadrigemina* are, on the other hand, pale. With regard to the nerve-fibres, it is certain that the upper part of the cerebral peduncle, *i.e.*, the *crura cerebelli ad corpora quadrigemina* (the continuations of the olivary columns, part of the restiform bodies and the *eminentiæ teretes*), enter the ganglia in question; still I have not, hitherto, succeeded in ascertaining anything definite about their course. I believe I am warranted in stating, that at least the greater part of these bundles do not pass into the medullary substance of the hemispheres, because, on the one hand, the most of the fibres fall from their original diameter of 0·0012‴ to 0·004‴, 0·001‴, and less; and, on the other, no trace of such a transition is found on the side of the *optic thalamus,* which is directed towards the medullary substance.

The superficial white covering of the ganglia in question is, however, to be excepted, which, at any rate, may establish a connection between them and the hemispheres, as its fibres, of 0·001‴ to 0·003‴, or even more, being arranged in bundles, and decussating horizontally in various directions, do not appear to terminate in the *thalami.* In like manner, the relation of the optic nerves to the *optic thalami* and *corpora quadrigemina*, and of the fornix to the latter, is not well made out, so that it is the more satisfactory, at all events, to be able to answer, with some degree of certainty, another important question. If the outer part of the *optic thalamus* be examined, it is found that it adjoins a considerable mass of white substance, which, at first sight, appears as a continuation of the base of the cerebral peduncle, passing externally and inferiorly upon the *optic thalami,* between the lenticular and caudate nuclei of the *corpus striatum*, to enter directly the medulla of the hemispheres. On closer inspection, it is seen that the white substance, as was mentioned above, in part enters into the *corpora striata,* particularly into the lenticular nuclei; in part radiates from without inwards, *from the hemispheres into the* *optic thalamus*. That is to say, very numerous white bundles, even visible to the naked eye, pass from the hemisphere into the *thalamus* in its whole depth, run towards the upper surface, the superior internal border and toward the *pulvinar*, and are lost exactly like the fibres which are continued from the cerebral peduncle to the *corpus striatum*; *i. e.*, these bundles, which at first contained elements of from 0·0012‴ to 0·0025‴ in diameter, split up into extremely dense plexuses of the very finest fibres, of from 0·0004‴ to 0·0008‴, the true terminations of which cannot be followed.

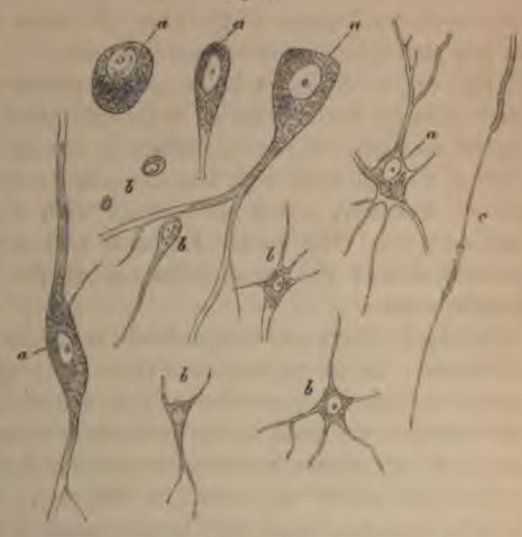
I may still notice the structure of the parts which are connected with the above-described ganglia. The *substantia nigra* of the cerebral peduncles contains beautiful pigmentated cells. The *commissura mollis* has smaller cells with processes, and, for the most part, fine fibres. The *glandula pinealis* contains pale rounded cells without any processes, and but a few nerve-fibres, 0·001‴ to 0·002‴ in diameter; and, for the most part, a large quantity of sandy particles (see § 117). The floor of the third ventricle, the *corpus mammillare* and *tuber cinereum*, contain nerve-cells mixed with numerous fibres of the finest kind. The *hypophysis cerebri* contains, in its anterior reddish lobe, no nervous elements, but rather, according to *Ecker*, the elements of a vascular gland, *i. e.*, a stroma of connective tissue, with very closely packed, wide blood-vessels, in the meshes of which there lie vesicles [cells?], of 0·030 to 0·090 of a millimetre in diameter, which sometimes contain only nuclei and a finely granular substance, sometimes distinct cells; in older subjects, also, a substance resembling colloid. The posterior smaller lobe consists of a finely granular substance, with nuclei and blood-vessels, and possesses, also, fine varicose nerve-tubes, which, like the vessels, descend to it from the *infundibulum*.

I regard the demonstration, that the fibres of the cerebral peduncle terminate in the ganglia (probably in the cells) of the brain, and that the white substance of the hemispheres consists of peculiar tubes, extending from the convolutions into the ganglia, and perhaps, also, into the medulla oblongata, without becoming connected with those of the cerebral peduncle, as one of the most important results which I have arrived at in my investigations into the central nervous system; seeing that by this means the long supposed separation of the animal and psychical spheres of the central nervous system is for the first time anatomically demonstrated; and it is explained why the white substance of the hemispheres, when stimulated, occasions neither pain nor movement.

§ 116. *Hemispheres of the Cerebrum.*—The white substance of the hemispheres of the brain consists throughout of nerve-tubes, of 0·0012‴ to 0·003‴, on an average 0·002‴, in diameter, without any intermixture of grey substance. These fibres, concerning the special course of which but little is as yet known, never run in the form of networks or bundles, but all parallel to each other, and mostly in a straight direction. They undoubtedly proceed outwards from the *corpus callosum* and the ganglia of the cerebrum to the superficial grey substance; but it is uncertain whether or not they divide in their progress. Besides the fibres now spoken of and those of the anterior commissure, the fornix and the origin of the optic nerves, the hemispheres contain other fibres, which decussate with them at right angles. I found these last upon the outer side of the *corpus striatum* and in the most superficial layers of the white substance, not far from the grey covering of the convolutions, where they are met with in not inconsiderable numbers, and in part taking an oblique course; but nothing can be ascertained with reference to their source. The grey substance of the convolutions is, as regards its intimate structure, tolerably clear (see my *Micr. Anat.*, tab. iv. fig. 2). It may be most fitly divided into three layers: an external, *white*; a middle, *pure grey*; and an internal, *yellowish-red*. The latter, which equals the two others in thickness, usually has, on its outermost limit, a clearer, frequently almost white streak, and occasionally, further inwards, a second narrower and less white layer, so that three, four, or even six layers are formed in the grey substance, viz., 1. yellowish-red layer, inner part; 2. first white streak; 3. yellowish-red layer, outer part; 4. second white streak; 5. grey layer; 6. superficial white layer. The grey substance contains, throughout its whole thickness, both nerve-cells and nerve-fibres, together with a large quantity of a granular matrix, exactly like that of the cerebellum. The nerve-cells, which are most numerous in the middle grey layer, are rather small, all having probably one to six processes ramifying in various ways, and, at last, running out into extremely fine pale fibrils, of about 0·0004‴ in diameter.

The nerve-tubes of the grey substance of the convolutions, as can be readily demonstrated, come from the medullary substance of the hemispheres, and penetrate in bundles, and parallel to one another, into the yellowish-red layer, in a straight direction. Here a number of the tubes separate from the bundles, and traverse the yellowish-red layer in all directions, but especially parallel to the surface, decussating accordingly with the main bundles. Where these horizontal fibres are collected in larger numbers, the above-described whiter or lighter streaks on this layer are produced, the outer of which is situated exactly at the place where the bundles penetrating the grey substance are lost to view. That is to say, as these bundles proceed further outwards they become continually thinner, by giving off lateral branches, and by the attenuation and separation of their elements, till, arrived at the grey layer, they are withdrawn from view; and although, when more narrowly traced, they can be demonstrated, even in this situation, as variously interlaced fibrils of the finest description, with scarcely any appearance of dark contours, only a few of them retain their original breadth and dark contours after reaching the pure grey layer, and continue in a straight or oblique course through it, in order to pursue their way further, horizontally, in the outer white layer. In this layer a considerable number of tubes, of the finer and very finest kind (fig. 97), decussate in various directions, in several super-imposed layers. These are obviously derived principally from the tubes which come from the greyish-red layer, and perhaps, also, as *Remak* assumes, from the knee of the *corpus callosum* at the base of the brain.

Fig. 97.



From the inner parts of the grey layer of the convolutions of the human brain; magnified 350 times. Nerve-cells, *a*, larger, *b*. smaller; *c*. nerve-fibres with axis-cylinder.

The relation of these fibres to the cells in the white layer is doubtful; but this much is certain, that many of them turn back into the greyish-red layer whence they come, — in other words, form loops, which were first described by *Valentin*, and which I have frequently and distinctly seen in chromic acid preparations treated with caustic soda. In like manner I saw in the greyish-red substance, as well as upon its convexity, directed towards the surface of the brain, separate loops with closely approximated sides. The bundles of the greyish-red substance contain, at first, tubes of 0·0012‴ to 0·003‴ in diameter, nearly all of which finally diminish to 0·001‴, and, in the grey substance, assume the smallest diameter of the nerve-tubes, viz., 0·0004‴ to 0·0008‴. The fibres given off from these bundles within the greyish-red layer are, in part, of the same diameter as in the bundles, as is especially the case with those of the thicker white streak, and, in part, finer. The fibres passing from the bundles into the superficial white substance are also, as a rule, thicker, up to 0·003‴; still there exist in this layer other very fine fibrils, of 0·0004‴. Although the connection of the fibres entering into the cortical substance with the nerve-cells has not, as yet, been actually demonstrated, still I do not hesitate in affirming it; and I regard the cortical substance as the place of origin of all the nerve-fibres of the hemispheres and *corpus callosum*.

The *corpus callosum* is composed purely of medullary matter, with parallel nerve-fibres of quite the same appearance and diameter as those of the medullary substance of the hemispheres. This is also the case with the *commissura anterior* and the *fornix*, which, however, comes in contact with the grey substance in various ways. The *cornu Ammonis* and the *hippocampus minor* present almost the same relations as the convolutions of the hemispheres.

Lastly, we have still to speak of the origin of the first two pairs of nerves. In the white part of the *tractus olfactorius*, the olfactory nerve contains fine nerve-fibres of from 0·0004‴, to at most 0·002‴, in diameter, the finest being pale-bordered, and probably non-medullated; also grey substance, composed of a finely granular matter, and cells of 0·007‴ to 0·008‴ in diameter. These cells and other smaller ones, down to 0·003‴ in size, many of them having branched processes, form the bulb of the olfactory nerve, intermingled with many fine fibres, whose relation to the cells and to the proper nerves of smell cannot be ascertained. The *nervus opticus*, with its tract divided into two crura, proceeds from the *corpora geniculata*, the *corpora quadrigemina*, and the *optic thalami*, and is, besides, connected with the cerebral peduncles, the *substantia perforata antica*, the *tuber cinereum*, and the *lamina terminalis*. Whence its fibres, which are dark-bordered tubes, of 0·002‴ in diameter, really arise, is, in man, unknown (judging from experiments on animals, they would seem principally to come from the *corpora quadrigemina*); on the other hand, we know that a part of them decussates in the *chiasma*. In the *chiasma* we find, moreover, as stated by various authorities, 1, fibres which do not decussate, but pass from the *tractus* into the optic nerve of their own side; and 2, commissural fibres, namely, *posterior*, which would form a commissure of the places of origin of the nerves of vision, and *anterior*, which can serve only to unite the *retinæ*. The existence of the first-mentioned fibres is certain, although they are much more scanty than the decussating elements; but that of the others, also, can scarcely be denied. A commissure of the *corpora quadrigemina* and *optic thalami* may, perhaps, be explained physiologically; but even a commissure of the *retinæ* cannot be regarded as impossible, since we know that the retina contains grey substance and nerve-cells with branched processes, from which the optic nerves arise

The discovery of *Turck* (*Sitz. der Wien. Akad.* 1851, March—June, 1853), that in diseases of the brain or cord certain tracts of fibres degenerate, and that especially compound granular cells become developed in them, appears destined to become important for the study of the course of the fibres in the central nervous system; and I would recommend, for the investigation of such cases, the employment of chromic acid preparations.

§ 117. *Membranes and Vessels of the Central Nervous System.*

A. *Membranes.* 1. *Spinal Cord.*—The *Dura mater* consists of parallel, mostly longitudinal bundles of connective tissue, and of a network of fine elastic fibres. Anteriorly, it is united with the *fascia longitudinalis posterior* of the vertebral column; posteriorly and laterally it is free, and separated from the arches of the vertebræ by an interspace in which there are loose anastomosing bundles of connective tissue, gelatinous fat, and cells containing serum. This space also contains the well-known *plexus venosi* and finer vessels. It is generally stated that the inner surface of the *dura mater* is covered by an outer layer of the arachnoid; but nothing is found here except an epithelium composed of polygonal cells, and there is not a trace of a special membrane. The *ligamentum denticulatum* possesses no epithelium, and, like the thickened stripes of the *pia mater*, to which it is attached, has exactly the same structure as the *dura mater*.

The *arachnoid of the spinal cord* consists of a single layer of great delicacy and transparency, corresponding in extent to the *dura mater*. Its outer surface is connected with the *dura mater* by means of dense bands or more delicate fibrils; in other respects, it is perfectly smooth and shining, and covered by a simple layer of pavement epithelium. Its inner surface is likewise smooth, but without epithelium; it is separated from the cord and the *cauda* *equina* by a large interspace, the *sub-arachnoid space*, but gives off numerous bands to the *pia mater* and the roots of the nerves, which, besides accompanying vessels and nerves, are especially well marked in the posterior median line, where they are collected in a linear series, so as in some measure to form a fenestrated, or even a perfect partition, especially in the neck. With reference to its intimate structure, the arachnoid principally contains reticulated, anastomosing bundles of connective tissue, of 0·001‴ to 0·004‴ in diameter, and scanty, fine elastic fibres.

The *pia mater* closely embraces the spinal cord and the grey substance of the *filum terminale*, passing, on the one hand, into the spinal cord at the anterior and posterior fissures, in the form of thin processes, and on the other, furnishing delicate sheaths to the roots of the nerves. It contains for the most part ordinary connective tissue, along with a few elastic fibres. In the *pia mater* of the cervical portion of the spinal cord, and also in other parts, fusiform or stellate brownish pigment cells are found, which, in the former place, frequently impart to it a brown colour.

2. *Brain.* The investments of the brain agree generally with those of the cord, but present certain differences. The *dura mater* consists here of the proper *dura mater* and the periosteum of the inner surface of the cranial bones, which are immediate continuations of the corresponding membranes of the vertebral canal, and coalesce at the level of the atlas. The cranial *dura mater* is in general thicker and whiter than that of the cord. Its outer, or periosteal lamella, which is whitish yellow and rough, is attached more or less firmly to the bones, supports the larger *vasa meningea*, and is richer in vessels than the inner proper *dura mater*, with which, at an earlier period, it is only loosely connected, and from which, except in the situation of the sinuses, it can be partially separated, even in the adult. The inner lamella has fewer vessels, is whiter, in many places with a tendinous lustre, perfectly smooth, and for the most part even, upon its inner surface. The processes of the *dura mater*,—the large and small *falx*, and the *tentorium cerebelli* — appear as prolongations of this inner lamella, and between the two lamellæ the sinuses of the dura mater are situated with but few exceptions. Both lamellæ contain connective tissue of the same form as that in the tendons and fasciæ. The inner surface of the *dura mater* is covered with a multiple layer of pavement epithelium cells, but has no other investment which could be regarded as a parietal lamina of the arachnoid.

The *arachnoid membrane* of the brain, likewise, presents only a single lamella, which also lies close to the inner surface of the *dura mater*; but, unlike that of the cord, it is, in many places adherent or even blended with the *pia mater*, especially upon all the convolutions and the projecting parts at the basis of the brain; and where this intimate adhesion does not exist, the two membranes are connected by numerous processes. Accordingly in the case of the brain also, there is no continuous sub-arachnoid space, but numerous larger and smaller spaces, only partially communicating with each other. The larger of them, which are found between the *cerebellum* and the *medulla oblongata* and below the *pons*, the cerebral peduncles, the Sylvian fissure, etc., or at least the former, pass directly into the sub-arachnoid space of the cord, whilst the smaller, corresponding to the *sulci*, over which the arachnoid extends like a bridge, may, perhaps, communicate with each other, but the majority of them at least are not connected with the above-mentioned larger spaces. The arachnoid is nowhere connected with the lining of the cerebral ventricles. Its structure is the same as that of the spinal arachnoid, and its outer surface is likewise furnished with an epithelium.

The *pia mater* of the brain is more vascular but more delicate than that of the cord, and invests all the elevations and depressions of the surface of the brain, with the sole exception of the bottom of the fourth ventricle, which it spans over, as the *tela chorioidea inferior*, in order, then, to be reflected at the inferior surface of the *vermis inferior* and *tonsillæ*. The *pia mater* penetrates into the interior of the brain only at one place, viz., at the transverse fissure of the *cerebrum*, where, enveloping the *vena magna Galeni* and the pineal gland, it enters beneath the *splenium corporis callosi*, and forms the *tela chorioidea superior* with the *plexus chorioideus ventriculi tertii*; then passing under the *corpus callosum*, it gives rise to the choroid plexuses of the lateral ventricles, which, between the crus cerebri and the middle lobe, are connected with the *pia mater* at the base of the brain. Besides its numerous vessels, the *pia mater* contains some indistinctly fibrous and connective tissue without elastic fibres, and occasionally, at the base of the brain, pigment cells.

The *telæ chorioideæ* and *plexus chorioidei* consist almost wholly of vessels, and have, on their free surfaces, a simple pavement epithelium, the cells of which mostly contain some pigment and fat-granules, and in the mammalia as also in the frog, are ciliated.

All parts of the cavities of the brain which are not connected with the continuations of the *pia mater*, i.e., the floor of the fourth ventricle, the aqueduct of Sylvius, the floor and lateral walls of the third ventricle, the fifth ventricle, the roof, the anterior and posterior horn, and a large part of the descending horn of the lateral ventricles, and the hollow within the olfactory bulbs in the embryo, possess a special investment, the so-called *ependyma ventriculorum* (fig. 98). This is a simple layer of epithelium, which is seated normally immediately upon the nervous substance; still there is so frequently developed under it a striated layer of connective tissue of 0·01‴ to 0·05‴ in thickness, that the occurrence of the latter may almost be regarded as constant at a certain age. In man it is ciliated, at least in certain places, and sometimes, perhaps, it is so all over.

Fig. 98.

Human ependyma. A. From the *corpus striatum*; 1. from the surface; 2. from the side; *a*. epithelial cells; *b*. subjacent nerve-fibres. B. Epithelial cells from the *commissura mollis*. Magnified 350 times.

The vessels of the above-described membranes present very various conditions. The *dura mater* of the cord is poor in vessels like the fasciæ. That of the brain, on the other hand, has many vessels, especially its outer layer, corresponding to a periosteum, which supports the meningeal arteries, partly for its own use, partly for the cranial bones which receive numerous branches; and which conducts by means of its veins, a part of the blood of the bones. The arachnoidea is non-vascular, whilst the *pia mater* both of the cord of the brain, not only supports the very dense ramifications of the vessels of the nervous substance, but also independently of the *plexus chorioidei* contains a considerable number of vessels of its own. *Fohmann* and *Arnold* assume the existence of *lymphatic vessels* in the *pia mater* of the surface of the cerebrum and cerebellum as also in the *plexus chorioidei*, but it is doubtful whether they occur here.

The membranes of the central nervous system possess, in part at least, *nerves* also. In the *dura mater* of the brain, some of the nerves run in the periosteal lamella of the membrane, following pretty closely the course of the meningeal arteries, and are especially distinct upon the middle meningeal artery, coming from the sympathetic and the *trigeminus*. They occur, moreover, upon the anterior and posterior meningeal arteries, and there is a *nervus tentorii*, from the fifth (*Arnold*), which also goes to the larger sinuses of the *dura mater*. Nerves are not known to exist in the *dura mater* of the cord, although they occur upon the venous sinuses of the vertebral canal.

The *pia mater* of the cord is everywhere rich in networks of fine nerves, which are not confined to the course of the vessels. At the base of the brain, numerous nervous plexuses exist upon the arteries of the *circle of Willis*, which, following the course of the different arteries, with trunks of, at most, 0·03‴ in diameter, spread out through the whole *pia mater* of the brain. Although their terminations can nowhere be recognised, *still I traced these nerves recently upon arteries of* 0·04‴ *and less in diameter into the substance of the brain itself.* The choroid plexuses and the arachnoid are destitute of nerves. All the nerves of the *pia mater* arise from the posterior roots of the spinal nerves, from the sympathetic, and from the roots of some of the cerebral nerves.

B. *Vessels of the Central Nervous System.* In the character and mode of distribution of their blood-vessels, the brain and the cord almost entirely agree. After the arteries have ramified to a considerable degree in the *pia mater*, they penetrate into the nervous substance, except at a few places (*substantiæ perforatæ, pons*) as fine, though still distinctly arterial vessels, and break up by continued ramification, mostly at acute angles, into a tolerably wide meshwork of very fine capillaries, from which the roots of veins arise, and unite to form the well-known trunks, both upon the surface and in the interior (fig. 99). The grey substance is invariably much more vascular than the white, the plexuses being much closer, and the vessels themselves somewhat narrower, to which circumstance its colour is partly due. In the spinal cord, the entering vessels are, in part, very regularly arranged in series. Two such series exist at the bottom of the anterior fissure, entering the grey substance, right and left from the process of the *pia*

Fig. 99.

Vessels of the cerebral substance of the sheep, after an injection of *Gerlach's*. *a.* of the grey, *b.* of the white substance.

mater; a third corresponds to the posterior fissure, and others not unfrequently correspond to the roots of the nerves and the attachment of the *ligamentum denticulatum*. All these vessels, without becoming narrower to any considerable degree, penetrate into the grey substance, and then form their terminal expansions. There are beautiful parallel vessels in the grey substance of the cerebellum, and also, but less distinct in the cerebrum and other parts, with the exception of the thalamus. The structure of the vessels is, in general, the same as in other parts, still the external coat or *adventitia* of the arteries is soon converted into a simple homogeneous envelope, and the veins have mostly not a trace of muscular fibres in their walls. Beside these vessels, the brain, like the cord, as *Virchow* perhaps correctly supposes, appears to contain a *homogeneous matrix of connective tissue*, which supports the nervous elements.

In the cerebral ventricles, there exists an extremely small quantity of a serous fluid, which is obviously secreted by the vascular plexuses. A second fluid, the *liquor cerebro-spinalis*, is contained in the above-described sub-arachnoid spaces, and may be readily obtained from the largest of them, which extends from the base of the brain to the end of the sac of the spinal *dura mater*. This fluid is alkaline, contains 98·56 water, ·055 albumen and extractive matter, 0·84 salts, especially chloride of sodium, and its chief purpose appears to be to facilitate the movement of the central nervous system, and to act as regulator in the different conditions of fulness of the vascular system.

We may here annex some observations on the *pathological* conditions of the structures in question. The *ependyma ventriculorum* has frequently, especially in dropsy of the ventricles and in old age, an extremely thickened fibrous layer, which, as was first stated by *Purkinje*, constantly contains round or oblong yellowish bodies, with a concentric striation resembling starch-granules, and consisting, as *Virchow* has discovered, of a substance allied to starch and to cellulose; being rendered blue by iodine, and violet by iodine and sulphuric acid. These *corpora amylacea*, which are obviously pathological products, frequently exist in incredible numbers in the cortical substance of the brain, in the medullary substance of the cord, the *filum terminale*, the *retina*, in the human *cochlea*, in the grey nucleus of the cord, in the olfactory, auditory and optic nerves. There is found, further, in the *plexus chorioides*, in the pineal gland, occasionally in the *pia mater* and arachnoid (also in the cord), and, although rarely, in the walls of the ventricles, as a constant but pathological product, the so-called *brain-sand* (*acervulus cerebri*). It consists of rounded, simple or mulberry-shaped, dark, mostly concentrically striated globules, 0·005‴ to 0·05‴, and, together with these, of masses of irregular form. It contains chiefly carbonate of lime, with phosphate of lime, magnesia, and an organic substance, which, after the extraction of the salts, completely retains the form of the concretion, and appears as a concentrically stratified, pale mass. It is quite certain, that this brain-sand when it appears as elongated, branched or reticulated masses, is simply developed in the bundles of connective tissue, as not unfrequently occurs in the pineal gland and in the membranes of the brain; in other cases it appears to be an independent incrustation of fibrine-coagula. On the other hand, *cells* impregnated with calcareous matter, do not occur. Lastly, we have still to notice the *glands of Pacchioni* and the *ossifications* of the cerebral membranes. The former, which are principally situated at both sides of the base of the greater *falx*, and at the border of the great longitudinal fissure of the brain, upon the *flocculi*, in the choroid-plexus, etc., consist chiefly of a dense fibrous substance, resembling immature connective tissue, and also contain undeveloped elastic tissue, brain-sand and *corpuscula amylacea*. The ossifications, which are true bone-plates, are met with partly upon the inner surface of the *dura mater* of the brain, partly upon the arachnoid, particularly of the *cauda equina*.

Peripheral Nervous System.

§ 118. *Nerves of the Spinal Cord.*—The 31 pairs of nerves coming from the cord, arise, with few exceptions, by means of anterior and posterior *roots*. These, receiving a delicate investment from the *pia mater*, pass, converging towards each other, through the sub-arachnoid space, and then penetrate, independently of each other, the *arachnoidea* and *dura mater*, which latter furnishes them with a firmer covering. In their further course, a ganglion is formed on the posterior roots by means of the deposition around and between their nerve-fibres, of ganglionic cells, which, to all appearance, serve as origin to special nerve-tubes, the *ganglionic fibres of the spinal nerves*. These generally arise singly from cells, and have nothing in common with the fibres of the posterior roots which only pass through the ganglion, further than that, in their invariably peripheral course, they become applied to them, and mingle with them. The motor root never contains ganglionic cells, but goes past the ganglion, after lying more or less close to it. Beyond the ganglion, the two roots unite in such a manner that their fibres become intimately mixed and form a common nervous trunk, which contains sensitive and motor elements in all its parts. The nervous trunk so formed, usually becomes connected with the neighbouring upper and lower nerves, to form the well-known nervous plexuses, and, finally, gives off its terminal branches to the muscles, skin, vessels of the trunk and extremities, to the articular capsules, the tendons and the bones. As in the roots, so in the branches of the common trunk, we find that the motory chiefly contain thick fibres, whilst those destined for the skin and the other above-mentioned organs have finer ones, still all the tubes become at length uniformly fine in their terminal distribution. The nerve-fibres of all the spinal nerves, appear to run quite isolated and without dividing in the and branches; towards their termination, on the other hand, divisions may frequently occur, and, at least in certain animals (mice, batrachian larvæ), also reticular anastomoses. The termination itself takes place, perhaps, everywhere, by means of free extremities.

§ 119. *The Structure of the Spinal Ganglia* is, in mammalia, difficult to investigate, yet I believe I can state the following with certainty. The sensitive roots, as far as I have hitherto been able to ascertain, enter into *no connection with the ganglionic globules in the ganglion*, but pass through in the form of one, or in large ganglia, of numerous anastomosing bundles, to be collected again beyond the ganglion, into one trunk, which then immediately mingles with the motor root. The most of the ganglionic globules, perhaps all, are themselves in connection, as it appears, with nerve-fibres, and in such a manner, that only one nerve-fibre, or two, very rarely several, arise from them. These fibres, which I call *ganglionic fibres*, proceed, in by far the greater part, perhaps all, in a peripheral direction; they join and reinforce the root-fibres, passing through the ganglion so that every ganglion is, accordingly, to be regarded as a source of new nerve-fibres.

Fig. 100.

A lumbar ganglion of a young dog, treated with caustic soda, and magnified 45 times. *S*. Sensitive root. *M*. Motor roots. *R, a*. Anterior branch of the spinal nerve. *R, p*. Posterior branch. *g*. Ganglion with the cells and ganglionic fibres, which reinforce the sensitive root.

For the investigation of the spinal ganglia, those of the fifth sacral and coccygeal nerves of man and of the smaller mammalia may be selected, and are to be examined after they have been teased out, or in the natural state, with the aid of acetic acid, but especially of diluted caustic soda. The chief constituents of the ganglia, the *ganglionic globules*, or *ganglionic cells* (fig. 101), possess a distinct external covering, are roundish, elongated or pear-shaped, and measure from 0·012‴ to 0·04‴ in diameter, the majority being 0·02‴ and 0·03‴. The contents of these are throughout finely granular, and not unfrequently in the neighbourhood of the nucleus, there is a collection of yellow, or yellowish brown, pigment granules, which are more numerous the older the cell is, and to which the yellow colour of the ganglia is mainly owing. These ganglionic cells are found in larger quantities at the surface of the ganglia between the neurilemma and the root-fibres; and, at least in man, also in the interior of the ganglia, where, collected in heaps, they fill up the meshes between the plexuses of nerve-tubes. The individual cells are maintained in their position and separated from the surrounding parts and from the nerve-tubes, by a special tissue, which, when the cells are isolated, appears as a special covering to each, and has, accordingly, been called the *outer sheath*; but it, in fact, forms a system of variously connected small partitions traversing the whole ganglion, and enclosing the several cells. This intermediate substance is obviously referable to connective tissue, and occurs in form of a sometimes more homogeneous, sometimes more fibrous matter, with interspersed flat, roundish nuclei of 0·002‴ to 0·003‴ in diameter; or in form of separate, elongated, triangular or fusiform cells, which correspond to the formative cells of the connective or of the elastic tissue.

In man, and in the mammalia, pale processes of 0·0015‴ to 0·0025‴ in diameter proceed from by far the most of the ganglionic cells; these exactly correspond to those of the central cells, are provided, however, with a special covering, and, as I discovered in 1844, each becomes continued into a dark bordered nerve-tube (fig. 101). The cells are mostly furnished with only one process, and are then called *unipolar*; yet in man and in mammalia, cells with two pale processes, which pass into two nerve-fibres, also occur, the so-called *bipolar cells*. Whether there be one or two fibres coming from a cell, they always proceed towards the periphery; at least in investigating very small ganglia only such fibres are seen, and *Stannius* also found, that in the bipolar cells of the calf, the two processes lay close together. It is difficult to determine whether cells without processes also occur in spinal ganglia, since the processes readily break off, and mutilated cells are very apt to be taken for apolar cells. The dark-bordered fibres arising from the ganglionic cells, simply form the continuations of the pale processes of the cells, the coverings and contents of both parts passing continuously in each other, so that the membrane and the contents of a cell are connected with the sheath of a nerve-tube, and with the medullary sheath, together

Fig. 101.

Branch of the human *nervus coccygeus* within the *dura mater*, with an attached pedunculated ganglion-globule in its nucleated sheath, in which the commencement of the fibre is very evident. Magnified 350 times.

with the axis cylinder. In older ganglionic globules, or after the action of re-agents (arsenious acid, chromic acid, iodine), the contents of cells, as was first demonstrated by *Harting*, separate from the membrane, and the axis cylinder appears as a direct continuation of them (fig. 102). The ganglionic fibres, frequently surrounding the cells in an arched form or in several coils, are, at first *fine*, of 0·0015''' to 0·0025''' in diameter. They do not, however, remain so, but, as may in many cases be very readily observed directly, increase very soon in thickness, so that even within the ganglion, all measure 0·003''' and 0·004''', many even 0·005''' and 0·006''', and have, consequently become *medium thick*, and *thick nerve-tubes*. The processes of the cells and the nerve-fibres arising from them possess, like the cells themselves, nucleated sheaths, the so-called *sheath processes*; they lose them, however, at the point where they enter the trunk passing out of the ganglion, and then receive the ordinary neurilemma of the nerves as a covering.

Fig. 102.

Ganglion globule from the pike (so called *bipolar*), running out at both ends into dark-bordered nerve-tubes, treated with arsenious acid, and magnified 350 times. *a*. Envelope of the globule. *b*. Nerve-sheath. *c*. nerve-medulla. *d*. The nerve-fibre connected with the contents (*e*) of the ganglion-globule which are retracted from the envelope.

The account I have just given of the relation of the spinal ganglia of man and mammalia, deviates very considerably from what *Bidder*, *Reichert*, *R. Wagner* and *Robin*, in 1847, found to be the case in fish. The main difference consists in this, that whilst in mammalia, as far as we know, the roots enter into no direct relation to the ganglionic cells, and simply pass through the ganglia, in fishes all the nerve-fibres are connected with them, each fibre being interrupted by a bipolar cell, without any special ganglionic fibres at all.

§ 120. *Further Course and Termination of the Spinal Nerves.*—Beyond the spinal ganglion, the sensitive and motor roots join to form a common trunk, by intermixture of their fibres, as can be very distinctly observed in small animals. All subsequent off-sets from the anterior and posterior main branch, as well as from their further ramifications, are, consequently, of a *mixed* nature, and formed of fibres from both roots; this condition is maintained even to their last ramifications. Here, however, this relation becomes altered, the motor fibres going, in by far the greater majority, into the muscular twigs, and the sensitive into the cutaneous branches.

It cannot be ascertained anatomically where the ganglionic fibres, which *arise* in the spinal ganglia, are distributed. When their physiological relations, however, are considered, it seems most probable that they do not, or at least not all, as one might at first be inclined to believe, join the sympathetic in the *rami communicantes*, but running along with the spinal nerves, pass especially into the vascular branches, and are, consequently, distributed in the skin, muscles, bones, joints, tendons, and membranes (*periosteum, pia mater*, etc.), and perhaps, also, in the glands and involuntary muscular tissue of the skin. The nerve-fibres in the main divisions of the spinal nerves present the same diameter as in the roots, *i.e.*, there are finer and thicker tubes, and a certain number of transitional forms. Further on, however, the fibres separate, the thicker passing more into the muscular branches, and the thinner into the cutaneous nerves. According to the statements of *Bidder* and *Volkmann*, the relation, in man, of the thin to the thick fibres in the nerves of the skin is as 1·1 : 1; in the muscular nerves, as 0·1—0·33 : 1. I can only confirm these statements, and may add that the nerves of the bones contain one-third thick, two-thirds thin tubes in the trunks, whilst those of the joints, tendons, and membranes contain chiefly thin fibres.

The spinal nerves consist, in general, of parallel tubes, mostly with an undulating course, to which circumstance, also, their transversely banded appearance is due; but present, however, in their course very frequent conjunctions, by which the different larger and smaller *plexuses*, with their decussating fibres, are produced. These plexuses are formed by an exchange of whole bundles of fibres, never by a coalescence of the individual primitive fibres, and present, in a microscopical point of view, nothing worthy of note. As far as is hitherto known, *divisions of the nerve-tubes* do not occur in the trunks and larger branches of the spinal nerves of mammalia, and, in like manner, there is not any considerable change in their diameter; but, on the other hand, even in man, such divisions, and, at the same time, a very considerable decrease of the diameters of the tubes, takes place in the terminal ramifications. With reference to these particulars and the nerve-terminations in the skin, muscles, bones, and membranes in general, we refer the reader to the more detailed description given in the paragraphs treating of the parts in question.

One mode of termination of the spinal nerves has here still to be mentioned, that in the *Pacinian bodies*. These bodies, called so by *Henle* and me (*Ueber die Pacin. Körperchen d. Menschen und* *der Thiere. Zürich.* 1844.) after Professor *Pacini*, of Pisa, are of an elliptical or pyriform shape, of a transparent whitish colour, with a whiter streak in the interior, and of ½‴ to 2‴ in size. In man, they are constantly found upon the cutaneous nerves of the palm of the hand and sole of the foot, seated in the subcutaneous tissue, and most numerously in the fingers and toes, especially in the third phalanges. In exceptional cases, they occur also upon other spinal nerves; and it may here, moreover, be stated, that they are invariably to be found on the branches of the large sympathetic plexus before and alongside the abdominal aorta, behind the peritoneum, especially in the neighbourhood of the pancreas; often, also, in the nerves in the mesentery, nearly as far out as the intestine. The structure of the Pacinian bodies is, upon the whole, simple (fig. 103). Each consists of very many (20 to 60) concentric layers of a somewhat homogeneous connective tissue, with numerous delicate plasma-cells. The outer layers are separated by larger, the inner by smaller interspaces, containing a clear serous fluid, whilst the cavity of the innermost layer is filled with a clear, finely granular substance furnished with delicate nuclei. Each body has a roundish pedicle, formed by the continuation of its membranous layers. This is connected with a nerve-twig, and contains a dark nerve-fibre, 0·006‴ to 0·068‴ broad, running into the Pacinian body. The fibre passes from the pedicle into the central cavity, is here reduced to 0·006‴ in breadth, and 0·004‴ in thickness, becomes *pale, non-medullated, almost like the axis-cylinder* of a nerve-fibre, and terminates in the upper part of the central cavity by a free, slightly granular knob, the extremity being

Fig. 103.

A human Pacinian body, magnified 350 times. *a*. Pedicle of the same; *b*. nerve-fibre in it; *c*. outer, *d*. inner layers of the envelope; *e*. pale nerve-fibre in the central cavity; *f*. division and termination of the same.

frequently bifid or trifid. These bodies occur in great numbers in many mammalia (most beautifully in the mesentery of the cat), and also in birds, in the skin, extremities, beak, and tongue (*Herbst, Will*); but their physiological import is as yet altogether obscure. Further information, including zootomical details respecting them, may be found in HERBST, *Die Pacinischen Körperchen*, Göttingen, 1847; BOWMAN, Art. *Pacinian Bodies*, in *Cycl. of Anat.*; and several papers quoted in my *Micr. Anat.*

The spinal nerves, at their exit from the *dura mater*, are enveloped by a firm covering of connective tissue, the *nerve-sheath*, *neurilemma*, which also enters into the interior of the nerves with fine processes, and, as in the muscles, marks off larger and smaller fasciculi, and also penetrates, in form of delicate septa, between the individual tubes (fig. 104). In the terminal ramifications, where single fibres, or collections of a few fibres, still frequently possess an external sheath, the neurilemma appears as a homogeneous envelope beset with elongated nuclei, of 0·003‴ in diameter; and in this form it is found also in the smaller branches of the cutaneous and muscular nerves, only that the substance there begins gradually to split up into longitudinal fibres, the nuclei lengthen out to from 0·005‴ to 0·008‴, often almost as in smooth muscles, and plasm-cells and elastic fibrils appear, which latter often encircle whole bundles. Finally, in the larger nerves, ordinary connective tissue, with distinct longitudinal fibrils, as in fibrous membranes, intermingled with a network of elastic fibres, makes its appearance, yet even here, particularly in the interior, there occur immature forms of connective and elastic tissue.

Fig. 104.

Transverse section of the *nervus ischiadicus*; magnified 15 times. *a*. General investments of the nerve; *b*. neurilemma of the tertiary bundles; *c*. secondary nerve-bundles, in part with special sheaths. From the calf.

All the larger nerves contain vessels, although not in great numbers, running principally in the longitudinal direction, and forming a loose network of fine capillaries, of 0·002‴ to 0·004‴, with elongated meshes, which invests the bundles, and, in part, enters between the elements of them, yet never surrounds the individual primitive fibres, but always collections of them. The ganglia contain beautiful reticular capillaries in the form of a meshwork, each ganglion-globule being surrounded by special vessels. The Pacinian bodies also contain vessels, which penetrate even into the central cavity (TODD and BOWMAN, i., pp. 75, 76; HERBST, tab. iv., figs. 1 and 2).

§ 121. *Cerebral Nerves.*—The sensitive and motor nerves, arising from the brain, agree so closely with the spinal nerves, that a short description of them is sufficient, while the specialities of the higher nerves of sense will be afterwards considered along with the organs of the senses. As regards their roots, as well as their course and distribution, the motor cerebral nerves, the third, fourth, sixth, seventh, and twelfth pair present quite the same relations as the motor roots and muscular branches of the spinal nerves, with the single exception, that by communications with sensitive nerves, some sentient fibres, destined for the muscles, are mingled with all of these nerves. It is worthy of remark, that, according to *Volkmann*, the small root of the *hypo-glossus* of the calf, which is provided with a ganglion, excites motorial effects. The signification of this occurrence of ganglionic globules in motor nerves has not hitherto been made out. Probably, simple fibres with peripheral distribution arise from them, exactly as in the spinal ganglia; at any rate, it shows that ganglia are not necessarily restricted to sensitive nerves. The fifth, ninth, and tenth pairs resemble the spinal nerves in so far as they all contain motor and sensitive elements. In the *trigeminus*, the small root contains principally motor thick tubes; the large, many fine fibres. The *Gasserian* ganglion contains numerous larger and smaller ganglion-globules, of 0·008‴ to 0·030‴, with nucleated sheaths, and, according to what I have observed in small mammalia and in man, presents the same relations as a spinal ganglion, *i.e.*, it allows the fibres of the large root simply to pass through, and, from unipolar cells, gives origin to numerous moderately thick nerve-fibres, which join the branches passing out of the ganglion. Bipolar cells also occur, but, as it appears, in smaller numbers; and as for the apolar cells, the same holds good as in the spinal ganglia. The terminal distribution of the *trigeminus* is, for the most part, the same as that of the cutaneous nerves in general, which is described in detail elsewhere. The *nervus lingualis* possesses *peripheral ganglia*. With regard to the larger ganglia occurring on the *trigeminus* (*ganglion ciliare, oticum, spheno-palatinum, linguale, supra-maxillare*), I find that their structure is more like that of the sympathetic ganglia, only they contain a considerable number of larger ganglion-globules. The *glosso-pharyngeus*, although endowed with motor properties, possesses, nevertheless, according to *Volkmann*, no fibres which do not traverse the one or the other of its ganglia. The ganglia of the *glosso-pharyngeus* present the same relations as the spinal ganglia; in the tympanic cavity and the tongue, its terminations contain small ganglia, and otherwise agree with those of the *trigeminus (P. major)*. The *vagus* in man enters with all its roots into the *ganglion jugulare*, whilst in some mammalia (dog, cat, rabbit, and sheep, but not in the calf), it has a smaller bundle of origin, which is not concerned in the ganglion. In the *ganglion jugulare*, and in the *intumescentia ganglioformis*, I have never been able to discover anything deviating from the structure of a spinal ganglion, only some of the ganglionic cells fall to 0·009‴ in diameter. In its termination this nerve presents a constant mode of distribution of the thicker and thinner fibres, so that the branches to the *œsophagus*, heart, and stomach, contain almost exclusively thin fibres; whilst in those to the lungs and in the *laryngeus superior*, the thin fibres are to the thick as 2 : 1, and in the *laryngeus inferior* and the *rami pharyngei*, as 1 : 6—10. These fine fibres do not all come from the sympathetic, since they are found in large proportion in the roots of the *vagus*, and they are also very numerous in the *laryngeus superior*. Besides, many of them may be nothing else than attenuated or originally finer ganglionic fibres, as they are called, arising from the *ganglia* of the *vagus* itself, and which I am not disposed to refer to the sympathetic. With respect to the terminations of the *vagus*, see below, in the paragraphs treating of them. The *accessorius Willisii*, although, perhaps, also sensitive in part, possesses no ganglion-globules, and, as far as is known, exhibits nothing peculiar in its distribution and termination.

§ 122. *Ganglionic Nerves*.—This name is, perhaps, the most fitting wherewith to designate the so-called *sympathicus*, the *sympathetic* or *vegetative nervous system*, since it presupposes no physiological hypothesis, but simply expresses the fact which, anatomically, is most conspicuous. The ganglionic nerves are neither a wholly separated part of the nervous system (*Reil, Bichat*), nor a mere section of the cerebro-spinal nerves, but, on the one hand, they exist quite independently, in virtue of very numerous nerve-fibres arising in their ganglia, *ganglionic fibres of the sympathetic*; while, on the other, they are also connected with the cord and brain by means of a small number of fibres, which they receive from other nerves.

If we compare the ganglionic and the cerebro-spinal nerves, we find that the former, derived as they are from a two-fold source, we find that the motory chiefly contain thick fibres, whilst those destined for the skin and the other above-mentioned organs have finer ones, still all the tubes become at length uniformly fine in their terminal distribution. The nerve-fibres of all the spinal nerves, appear to run quite isolated and without dividing in the and branches; towards their termination, on the other hand, divisions may frequently occur, and, at least in certain animals (mice, batrachian larvæ), also reticular anastomoses. The termination itself takes place, perhaps, everywhere, by means of free extremities.

§ 119. *The Structure of the Spinal Ganglia* is, in mammalia, difficult to investigate, yet I believe I can state the following with certainty. The sensitive roots, as far as I have hitherto been able to ascertain, enter into *no connection with the ganglionic globules in the ganglion*, but pass through in the form of one, or in large ganglia, of numerous anastomosing bundles, to be collected again beyond the ganglion, into one trunk, which then immediately mingles with the motor root. The most of the ganglionic globules, perhaps all, are themselves in connection, as it appears, with nerve-fibres, and in such a manner, that only one nerve-fibre, or two, very rarely several, arise from them. These fibres, which I call *ganglionic fibres*, proceed, in by far the greater part, perhaps all, in a peripheral direction; they join and reinforce the root-fibres, passing through the ganglion so that every ganglion is, accordingly, to be regarded as a source of new nerve-fibres.

Fig. 100.

A lumbar ganglion of a young dog, treated with caustic soda, and magnified 45 times. *S.* Sensitive root. *M.* Motor roots. *R. a.* Anterior branch of the spinal nerve. *R. p.* Posterior branch. *g.* Ganglion with the cells and ganglionic fibres, which reinforce the sensitive root.

For the investigation of the spinal ganglia, those of the fifth sacral and coccygeal nerves of man and of the smaller mammalia may be selected, and are in the spinal ganglia, only they are, on an average, smaller, ranging from 0·006‴ to 0·018‴ in diameter, the mean being from 0·008‴ to 0·01‴, less deeply coloured with pigment, or even colourless, and generally rather uniformly rounded. As to the origin of the *nerve-fibres of the gangliated cord*, it is especially obvious, that the greater part of them come from the *rami communicantes* which arise from the trunks of the spinal nerves immediately beyond the spinal ganglia; they are formed, in general, like the sensitive roots of these (*i.e.*, principally contain finer fibres); and, whether one or more from each spinal nerve, are distinctly connected with both its roots. According to all that has hitherto been ascertained, the fibres of these connecting branches spring principally from the spinal cord and spinal ganglia, and are, consequently, roots of the sympathetic; a smaller part of them, however, may come from the sympathetic, and joining the spinal nerves, be distributed with them peripherally. Having entered the gangliated cord of the sympathetic, the *rami communicantes*, in so far as they arise from the spinal nerves, almost invariably divide into two or several branches, and run upwards and downwards in the main cord towards its cephalic and pelvic extremities; and then joining the longitudinal fibres, they all gradually pass off into the peripheral branches.

Fig. 106.

From the human sympathetic nerve; magnified 350 times. A. A piece of a grey nerve, treated with acetic acid; *a*. fine nerve-tubes; *b*. nuclei of *Remak's* fibres. B. Three ganglion-globules, one with a pale process.

Besides the finer and thicker fibres of the *rami communicantes*, the cord of the sympathetic contains other very numerous dark-bordered, but pale, fine nerve-tubes, of 0·0012‴ to 0·002″ in diameter, concerning which I unhesitatingly assert that they arise in it, and are not merely continuations of the fibres of the *rami communicantes*, as has been lately supposed, since the discovery of bipolar ganglion-globules in fish. According to all that I have seen in mammalia and in man, the sympathetic ganglia agree with those of the spinal nerves in so far, that they contain chiefly unipolar, more rarely bipolar cells; they differ, however, in this respect, that apolar cells are certainly present in them in larger quantity, and that their ganglionic fibres are invariably the finest which are met with in peripheral nerves, and probably, in most cases, pass from the ganglia in various directions. According to *Remak*, *multipolar cells* also occur in the ganglia of the sympathetic. To trace topographically different fibres in the sympathetic cord, with reference to their origin from determinate *rami communicantes* and ganglia, and their continuation into particular branches — if more be required than what has already been stated — is a problem as yet not to be undertaken, and which can only be reserved for the future.

Bidder and *Volkmann* have demonstrated, that in the frog the majority of the fibres of the *rami communicantes* are distributed with the spinal nerves in the periphery, and, accordingly, only a small part, which, besides, is derived from the spinal ganglia, is to be regarded as the root of the sympathetic. However, I believe I have seen in man and in rabbits the *rami communicantes* running principally in a central direction.

This appears to be the proper place to make a few more remarks upon the *fine fibres* of the ganglionic-nerves. It has long since been known, that the sympathetic contains far more of the thinner nerve-fibres than the cerebro-spinal nerves; but it was first in 1842, that *Bidder* and *Volkmann* endeavoured to show that they are not only thinner, but also otherwise anatomically different, whence, in contrast to the thick tubes of the cerebro-spinal nerves, they called them sympathetic nerve-fibres. In opposition to this, VALENTIN (*Repert.* 1843, p. 103), and I (*Symp.*, p. 10, *et seq.*), attempted to prove, and, as I believe, successfully, that the fine fibres in the sympathetic constitute no special class of fibres.

§ 124. *Peripheral Distribution of the Ganglionic Nerves.*—From the cord of the sympathetic, arise the branches going to the periphery. These invariably receive both fine and thick fibres from the main cord, but besides, at least in part, contain other special elements, to which their difference of aspect is owing. Some of them, namely, are white, as the trunk itself is in most places, the *nervi splanchnici*, for instance; others are greyish-white, as the *nervi intestinales* and the nerves of the non-pregnant uterus; others are grey, and at the same time less firm to the touch, as the *nervus caroticus internus*, the *nervi carotici externi seu molles*, the *nervi cardiaci*, the vascular branches in general, the branches connecting the great ganglia and plexuses of the abdominal cavity, the branches passing into the glands, and the pelvic plexuses. The peculiar condition of the latter nerves depends, in part, upon the paler colour of the fibres of the sympathetic itself, chiefly, however, upon the presence of *Remak's fibres*, as they are termed after their discoverer (gelatinous fibres, *Henle*), which were at first looked upon as a kind of nerve-tubes, but which are only a form of connective tissue, although there are still some authorities who have not been able to satisfy to be examined after they have been teased out, or in the natural state, with the aid of acetic acid, but especially of diluted caustic soda. The chief constituents of the ganglia, the *ganglionic globules*, or *ganglionic cells* (fig. 101), possess a distinct external covering, are roundish, elongated or pear-shaped, and measure from 0·012''' to 0·04''' in diameter, the majority being 0·02''' and 0·03'''. The contents of these are throughout finely granular, and not unfrequently in the neighbourhood of the nucleus, there is a collection of yellow, or yellowish brown, pigment granules, which are more numerous the older the cell is, and to which the yellow colour of the ganglia is mainly owing. These ganglionic cells are found in larger quantities at the surface of the ganglia between the neurilemma and the root-fibres; and, at least in man, also in the interior of the ganglia, where, collected in heaps, they fill up the meshes between the plexuses of nerve-tubes. The individual cells are maintained in their position and separated from the surrounding parts and from the nerve-tubes, by a special tissue, which, when the cells are isolated, appears as a special covering to each, and has, accordingly, been called the *outer sheath*; but it, in fact, forms a system of variously connected small partitions traversing the whole ganglion, and enclosing the several cells. This intermediate substance is obviously referable to connective tissue, and occurs in form of a sometimes more homogeneous, sometimes more fibrous matter, with interspersed flat, roundish nuclei of 0·002''' to 0·003''' in diameter; or in form of separate, elongated, triangular or fusiform cells, which correspond to the formative cells of the connective or of the elastic tissue.

In man, and in the mammalia, pale processes of 0·0015''' to 0·0025''' in diameter proceed from by far the most of the ganglionic cells; these exactly correspond to those of the central cells, are provided, however, with a special covering, and, as I discovered in 1844, each becomes continued into a dark bordered nerve-tube (fig. 101). The cells are mostly furnished with only one process, and are then called *unipolar*; yet in man and in mammalia, cells with two pale processes, which pass into two nerve-fibres, also occur, the so-called *bipolar cells*. Whether there be one or two fibres coming from a cell, they always proceed towards the periphery; at least in investigating very small ganglia only such fibres are seen, and *Stannius* also found, that in the bipolar cells of the calf, the two processes lay close together. It is difficult to determine whether cells without processes also occur in spinal ganglia, since the processes readily break off, and mutilated cells are very apt to be taken for apolar cells. The dark-bordered fibres arising from the ganglionic cells, simply form the continuations of the pale processes of the cells, the coverings and contents of both parts passing continuously in each other, so that the membrane and the contents of a cell are connected with the sheath of a nerve-tube, and with the medullary sheath, together

Fig. 101.

Branch of the human *nervus coccygeus* within the *dura mater*, with an attached pedunculated ganglion-globule in its nucleated sheath, in which the commencement of the fibre is very evident. Magnified 350 times.

with the axis cylinder. In older ganglionic globules, or after the action of re-agents (arsenious acid, chromic acid, iodine), the contents of cells, as was first demonstrated by *Harting*, separate from the membrane, and the axis cylinder appears as a direct continuation of them (fig. 102). The ganglionic fibres, frequently surrounding the cells in an arched form or in several coils, are, at first *fine*, of 0·0015‴ to 0·0025‴ in diameter. They do not, however, remain so, but, as may in many cases be very readily observed directly, increase very soon in thickness, so that even within the ganglion, all measure 0·003‴ and 0·004‴, many even 0·005‴ and 0·006‴, and have, consequently become *medium thick*, and *thick nerve-tubes*. The processes of the cells and the nerve-fibres arising from them possess, like the cells themselves, nucleated sheaths, the so-called *sheath processes*; they lose them, however, at the point where they enter the trunk passing out of the ganglion, and then receive the ordinary neurilemma of the nerves as a covering.

Fig. 102.

Ganglion globule from the pike (so called bipolar), running out at both ends into dark-bordered nerve-tubes, treated with arsenious acid, and magnified 350 times. *a*. Envelope of the globule. *b*. Nerve-sheath. *c*. nerve-medulla. *d*. The nerve-fibre connected with the contents (*e*) of the ganglion-globule which are retracted from the envelope.

The account I have just given of the relation of the spinal ganglia of man and mammalia, deviates very considerably from what *Bidder*, *Reichert*, *R. Wagner* and *Robin*, in 1847, found to be the case in fish. The main difference consists in this, that whilst in mammalia, as far as we know, the roots enter into no direct relation to the ganglionic cells, and simply pass through the ganglia, in fishes all the nerve-fibres are connected with them, each fibre being interrupted by a bipolar cell, without any special ganglionic fibres at all.

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It cannot be ascertained anatomically where the ganglionic fibres, which *arise* in the spinal ganglia, are distributed. When their physiological relations, however, are considered, it seems most probable that they do not, or at least not all, as one might at first be inclined to believe, join the sympathetic in the *rami communicantes*, but running along with the spinal nerves, pass especially into the vascular branches, and are, consequently, distributed in the skin, muscles, bones, joints, tendons, and membranes (*periosteum, pia mater*, etc.), and perhaps, also, in the glands and involuntary muscular tissue of the skin. The nerve-fibres in the main divisions of the spinal nerves present the same diameter as in the roots, *i.e.*, there are finer and thicker tubes, and a certain number of transitional forms. Further on, however, the fibres separate, the thicker passing more into the muscular branches, and the thinner into the cutaneous nerves. According to the statements of *Bidder* and *Volkmann*, the relation, in man, of the thin to the thick fibres in the nerves of the skin is as 1·1 : 1; in the muscular nerves, as 0·1 —0·33 : 1. I can only confirm these statements, and may add that the nerves of the bones contain one-third thick, two-thirds thin tubes in the trunks, whilst those of the joints, tendons, and membranes contain chiefly thin fibres.

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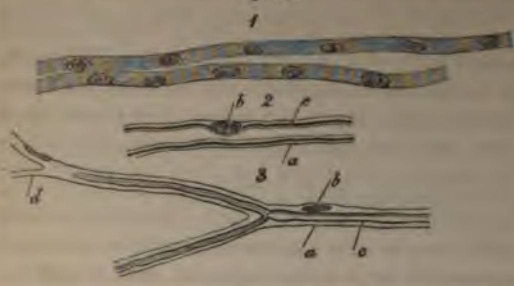
Fig. 107.

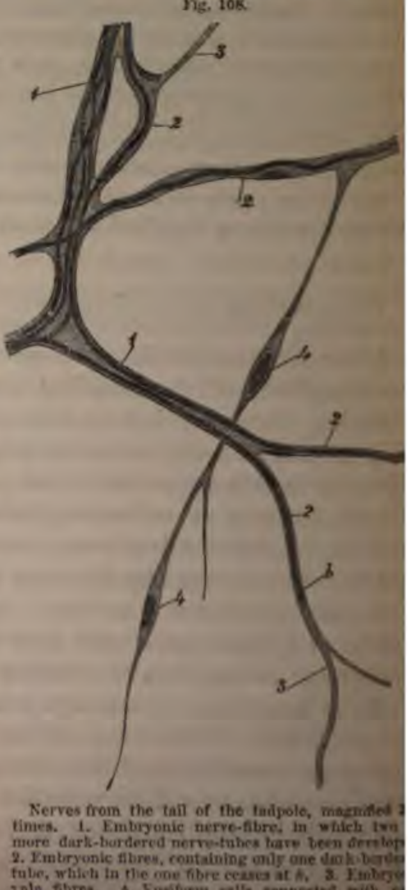


1. Two nerve-fibres from the *nervus ischiadicus* of an embryo 16 weeks old. 2. Nerve-tube from a newly-born rabbit. *a*. Envelope of the same. *b*. Nucleus. *c*. Medullary sheath. 3. Nerve-fibre from the tail of the tadpole. *a b c*. As above. *d*. The fibre still presents the embryonic character; the dark-bordered fibre shows a division.

With reference to the pro- duction of the white sub- stance, direct observation shows only this much, that the contents of the pale embryonic tubes gradually acquire darker and darker contours, and they finally appear as genuine dark- bordered fibres. Now, since it can be demonstrated, that the fibres, while becoming so altered, do not change their diameter, we may, perhaps, be warranted in assuming, that the white substance is formed by a chemical metamorphosis of a part of the contents of the primitive nerve- tubes, whilst the remain- der becomes the axis- cylinder.

The *development of the nerve-terminations*, which appears to differ in some respects from that of the nerve-trunks, may, as I have shown (*Annal. d. Sc. Nat.*,

Fig. 108.



Nerves from the tail of the tadpole, magnified times. 1. Embryonic nerve-fibre, in which two more dark-bordered nerve-tubes have been develop 2. Embryonic fibres, containing only one dark-borde tube, which in the one fibre ceases at *b*. 3. Embryo pale fibres. 4. Fusiform cells connected with other, and with a fully developed nerve-fibre.

1846, p. 102, tab. 6, 7), be traced with facility in the tail of the *larvæ* of the naked amphibia (fig. 107, 3; 108). Here we find, as the first rudiments of the nerves, pale branched fibres, 0·001‴ to 0·002‴ in diameter, which anastomose at certain places, and finally terminate in extremely fine fibrils, 0·0002‴ to 0·0004‴ in diameter. There is not the slightest difficulty in showing that these fibres arise by the coalescence of fusiform or stellated cells; for, firstly, we see such cells partly lying close to the fibres, but distinct from them, partly more or less connected with their off-shoots; and, secondly, we find, in the somewhat swollen places of division of the fibres, distinct cell-nuclei, and with them, at least in young larvæ, the well-known angular yelk granules, which originally fill all the cells of the embryo. At first the pale embryonic nerves are very few in number, and are limited to some short trunks lying close to the muscles of the tail; gradually, however, they are developed in a peripheral direction farther into the transparent parts of the tail, and in such a manner, that new cells continually become united with the nerve-trunks already present, whilst the latter unite with each other by means of slender off-shoots, almost like the capillaries of the same animal. These ramifications, when once formed, undergo further changes, as follows: Whilst the fibres gradually thicken to twice or four times their original diameter, dark-bordered fine primitive fibres are gradually developed in them, in the direction from the trunks to the branches, which, in no case, owe their origin to any newly superadded medullary sheaths, but are certainly formed only by the metamorphosis of a part of the contents of the pale fibres. The following relations, which have not hitherto been seen in the higher animals, are worthy of note: 1. The dark-bordered tubes scarcely ever entirely fill the pale fibres in which they arise, there being generally an interspace, often as wide as the fibres themselves, remaining between them and the sheath of the embryonic fibres, in which the nuclei of the primitive formative cells may occasionally be seen. 2. In the trunks and main branches, it is undoubted that several (2—4) dark-bordered tubes become developed within one and the same embryonic fibre; a very remarkable fact, proving the existence of dark-bordered tubes without structureless sheaths, and showing a correspondence with the muscular fasciculi, in which, likewise, many fine elements arise within one tube. Since the tails of tadpoles fall off at a subsequent period, unfortunately their interesting nerves cannot be followed to such a complete stage of development, as those of other parts. Still, in the oldest tadpoles, it is seen, that the nerves in question are somewhat thicker than at first, and that they terminate at the periphery, partly in the form of loops, partly with free ends, but in such a manner, that the primitive pale fibres are still present, and, proceeding from the dark-bordered ones, form an extremely fine ultimate nervous ramification with anastomoses and free extremities.

I should not have dwelt so long upon the nerves of the frog, were it not extremely probable that the facts observed will apply to numerous other nerve-terminations. This is certainly the case in those in the electric organ of the ray, which, even when fully developed, agree in many respects with those of well grown tadpoles, and, as ECKER has recently shown (*Zeitschrift für Wiss. Zoologie*, 1849, p. 38) are developed in exactly the same manner. The nerves in the skin of the mouse also obviously belong to this category; and, perhaps, it may hereafter be found, that, wherever peripheral nerve-divisions exist, their development takes place in essentially the same manner as I have here described.

But few investigations have been made with reference to the *development of the nerve-fibres in the central organs.* Of those of the ganglia I can only say this much, that they are later in being developed than those of the nerves, and, probably, from small fusiform cells, which are seen among the ganglion-globules. I once saw, in a spinal ganglion of a human embryo of four months, such a fusiform cell in connection with the process of a ganglionic globule. The development of the fibres in the cord and brain is extremely difficult to investigate; and it is best to make use of chromic acid preparations. In the human embryo, I find the formation of the tubes in question already commenced at the end of the second month, the white substance being distinctly striated, and containing, at different places, evidently fusiform, very delicate cells, which are partly isolated, partly connected, two, three, or several together. All these cells are at first pale, closely surround a nucleus, 0·002‴ to 0·003‴ in size, and have processes which are nearly as fine as the fibrils of connective tissue. In the fourth month, when the difference between the two kinds of substances is very distinct, we still, in parts, recognise nuclei in the fibres which have now become broader; at other parts, the nuclei have disappeared, although the fibres have not simultaneously acquired dark contours, which in fact are only developed after the middle of fœtal life, and first in the cord.

Respecting the subsequent changes of the nerve-tubes, it has already been remarked, that in part they increase very considerably in thickness. According to *Harting*, the fibres of the median nerve of the human embryo of four months, measure, on an average, $3{\cdot}4^{mm}$, in a newly born infant, $10{\cdot}4^{mm}$, in the adult, $16{\cdot}6^{mm}$. From the fourth month onwards, the increase in thickness of the nerves themselves appears, according to *Harting*, to depend simply and solely upon the enlargement of the already existing elements, since the fœtus and newly-born infant possess the same number of primitive fibres as the adult.

Extremely few *pathological changes* of the nerve-elements are known. In the nerve-cells of the brain, especially in old age, excessive deposits of pigment and deposits of fat are very frequently met with. *Valentin* believes he has seen a regeneration of ganglion-globules in the superior cervical ganglion of the rabbit, and *Waller* in the vagus ganglion of the rabbit, while, on the other hand, *Schröder* could find nothing of the kind. The nerve-tubes are easily destroyed by extravasations of blood, by tumours, by fibrous growth, etc., and by softening of the brain or cord, in which cases the white substance of the tubes breaks down into larger or smaller, very variously-shaped, coagulated or fluid masses, whilst the axial fibre seems to disappear.

In *atrophied nerves*, the nerve-tubes are thinner, readily break down, and, instead of white substance, are partly, often entirely, filled with small fat molecules. Nerves, when cut through, readily re-unite, and even pieces 8‴ to 12‴ long cut out of peripheral nerves, are replaced by true nervous tissue. Till quite recently, it was assumed, that, in these cases, the nerve-fibres simply coalesced, or were united by the new fibres formed between the two cut extremities; but *Waller* has lately asserted, that the nerve-fibres in the part of the nerve below or beyond the place of section always perish, and that the regeneration is effected by means of new fibres, which are developed between the necrosed nerve-fibres. According to *Waller*, the old nerve-fibres degenerate as far as their ultimate terminations, their white substance first coagulating and then breaking down into larger and smaller irregular masses, which at last entirely disappear.

How the new fibres, which are very pale, transparent and narrow, arise, is not stated by *Waller*, and it appears to me as still by no means proved, that such a formation takes place, seeing that I at least found no trace of such a formation in regenerated nerves, but observed numerous collapsed, non-medullated old tubes which, perhaps, subsequently receive medulla again. In fact, BRUCH also (*Zeitschrift f. Wiss. Zool.* vi.) believes he has seen a simple coalescence of the separated nerve-fibres. *Schiff* and *Lent* also found a short time since, that the fibres, which *Waller* regarded as new-formed, are nothing but the old tubes which have become non-medullated. When the ends of the nerves coalesce, these fibres receive anew their medulla, and consequently, *Waller's* hypothesis cannot be maintained. When a cut nerve does not heal, the peripheral end, contemporaneously with the extinction of the nervous activity, gradually alters in a particular manner. The nerve-tubes, as a whole, become yellowish, soft, friable, and lose their transversely-banded appearance, together with their lustre. The individual nerve-tubes no longer present a trace of double contours; their medulla is completely coagulated, and their breadth is very various (STANNIUS in MÜLL. *Arch.* 1847, p. 452); lastly, the medulla is wholly absorbed, and only pale tubes remain behind. In the rabbit and pigeon, according to *Brown-Séquard*, cut-wounds even of the spinal cord coalesce, and it can scarcely be doubted that the same result may take place in man. Hypertrophy of the nerve-substance itself is not known to occur, although that of the neurilemma has been observed. *Virchow* observed a new formation of fine nerves in pleuritic and peritoneal adhesions, and according to him, the grey substance on the walls of the cerebral cavities also appears capable of being regenerated. *Virchow* once found an accidental formation of grey and white nervous substance in an ovarian cyst.

§ 126. Respecting the *functions* of the nervous system, the following remarks, bearing more immediately on the anatomical facts, may here suffice. With reference to the two elementary constituents of the nervous system, anatomical examination shows that all the parts of the nervous system, which minister to its higher functions, contain grey substance in greater or less quantity — as the sympathetic, the ganglia of the spinal and cerebral nerves, the cord and the brain itself — while the nerves, acting only as conducting media, contain only nerve-tubes. This signification of the grey substance being accepted, it may be asked further, does it present differences in its structure as well as in its functions. With regard to this point, it is worthy of note, that the largest ganglionic globules exist in places whence motor effects proceed — as in the anterior horns of the cord between the fibres of the anterior roots, in the *medulla oblongata* at the origins of the motor cerebral nerves, in the cortical substance of the cerebellum, in the *pons Varolii* and in the cerebral peduncles — whilst, on the other hand, the smallest cells are found in the sensitive regions, as in the posterior horns of the cord, the *corpora restiformia* and *corpora quadrigemina*. There does not, however, appear to be a constant relation between the size of the cells and the sensitive and motor functions, for both kinds of fibres arise in the ganglia of the cerebro-spinal nerves and of the sympathetic and in the *optic thalami*; in the former from larger, the latter from smaller cells. Accordingly, just as in the case of the nerve-tubes, there appear to be large and small motor cells, and also sensitive cells of various dimensions; a conclusion which is confirmed by comparative anatomy, seeing that the large bipolar cells in fish are obviously sensitive. An essential distinction between sensitive and motor cells, whether they be of the same or different sizes, cannot be demonstrated, and any differences observed between these two kinds of cells are not greater than those between the motor cells of different localities. Even the cells of the cortical substances of the *cerebrum*, which physiology assigns as the seat of the mental functions, exhibit no peculiarities, perceptible by any means at our command. With regard to the *nerve-tubes*, anatomy fails to indicate distinctive characters in them in the sensient and motor nerves; a fact, however, which affords no adequate reason, in physiology, for assuming identity in their functions. Of the differences in thickness of the nerve-fibres, it may be remarked, that the manifold changes in diameter which all the fibres of the cerebro-spinal nerves undergo in their progress, are well calculated to show, that these conditions have, in general, nothing to do with the functions of the fibres. Nevertheless, I do not regard their differences of diameter as of no importance; and the attenuation of the tubes when they pass through grey substance, and their fineness as well as, in many cases, the absence of white substance at their origins and terminations, appear to me points of no small moment. On the assumption that the medullary sheath only represents a protecting soft covering for the delicate central fibre, and that the latter alone is the active and conducting medium, it can be easily comprehended why the dark-bordered nerve-tubes are more readily stimulated, wherever the medullary sheath is thin or absent, and the central fibre lies more free (as in the nerve-terminations in the eye, ear, olfactory organs, etc.). The finely dotted substance, which is found so often in the higher central masses, and supporting the most delicate nerve-tubes and cells, appears to me to have a similar protecting function.

Of the methods employed in *investigating* the nervous system, the chief have been already referred to in the preceding section. I may here call attention once more to the importance of chromic acid in examining the course of the fibres and the central nerve-cells, and to the great value of diluted caustic soda in indicating the nerve-tubes in transparent parts. The extreme proneness of the grey and white substance to undergo changes, particularly the tearing off of the processes of the nerve-cells and the varicosity, coagulation and breaking down of the nerve-tubes may be once more insisted on. The brain and cord are best studied in man, as also the elements of the ganglia; but, on the other hand, the course of the fibres in them and the nerve-terminations are best seen in small mammalia. To find out the small ganglia in the heart, *Ludwig* recommends treatment with phosphoric acid and solution of iodine in hydriodic acid, so diluted as to have merely a brownish tint. For study of the development, human and mammalian embryoes are very well adapted; but the batrachian larvæ, and, when opportunity offers, the electric organs of the embryo of the ray, should not be neglected, since in these the relations are by far most obvious.

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OF THE DIGESTIVE ORGANS.

I.—OF THE ALIMENTARY CANAL.

§ 127. The basis of the alimentary canal is formed by the so-called coats. The innermost of them, the *mucous membrane*, corresponds in structure to the external skin, and, like this, has, 1, a non-vascular covering, composed of cells — the *epithelium*; 2, a basis composed of connective and elastic tissue, containing vessels, nerves, and different forms of small glands; often, also, furnished with special outgrowths (*papillæ, villi*), and traversed by smooth muscular fibres — the *mucous membrane, strictly so called;* and 3, a layer of loose connective tissue, situated externally — *submucous tissue*. The second coat, the *muscular coat*, contains, for a certain extent, at the commencement and termination of the tube, transversely striped muscular fibres; in other parts, smooth muscular fibres, which elements mostly form two layers, an outer with longitudinal, and an inner with circular fibres, more rarely three distinct layers. Lastly, the third or *serous coat* exists only upon the part of the alimentary canal which lies in the abdomen and pelvis, and is a delicate, translucent, epitheliated membrane, with few vessels and nerves, which covers the tube and connects it with the walls of the abdominal cavity and with the abdominal viscera.

II.—OF THE ORAL CAVITY.

A. OF THE MUCOUS MEMBRANE OF THE ORAL CAVITY.

§ 128. The commencement of the alimentary canal has, so to speak, only one covering, the *mucous membrane*, which is more or less firmly attached to the bones and muscles bounding the oral cavity, and is distinguished especially by its not inconsiderable thickness and red colour, which is due to its copious supply of blood-vessels, as also by its numerous nerves and papillæ.

The *proper mucous membrane*, although continuously connected at the lips with the corium, and gradually passing into the latter, is more transparent and softer than the corium; it is, nevertheless, very firm and also more extensible. It consists, like the thinnest parts of the corium, of a single layer, 0·1‴ to 0·2‴ in thickness, ganglia, and in the small ganglia upon the urinary bladder of the *bombinator*, in which, as also in similar ganglia of the frog, the matter is as clear as possible.

It is still doubtful, how the nerve-tubes arising from these different sources — the *rami communicantes*, ganglia of the sympathetic cord and the peripheral ganglia — are related in their distribution. Many peripheral branches anastomose with others, and are then withdrawn from further investigation, as, for instance, the *nervi carotici externi* and *nervus caroticus internus*, the latter of which, containing almost solely fine fibres, with a large number of *Remak-fibres*, I do not regard as a root in the usual meaning of the word, but as a branch arising from the superior cervical ganglion, and, perhaps, the other cervical ganglia; further, the parts of the *nervi communicantes*, which run towards the periphery with the spinal nerves, the *rami cardiaci*, *pulmonales*, etc. Other branches become so fine in the parenchyma of the organs, that it is impossible to trace them for any great length. The following is all that has been ascertained with respect to their final course: 1. *Divisions of fibres* occur in the trunks and terminal ramifications of the sympathetic, as in the nerves of the spleen, of the Pacinian bodies in the mesentery, in the nerves accompanying the vessels in the mesentery of the frog, in those situated laterally on the uterus of rodent animals, then those of the lungs, heart and stomach of the frog and rabbit; in those of the dura mater on the arteriæ meningeæ, in the branches of the sympathetic of the sturgeon, in the cardiac nerves of *amphibia*, in the nerves of the urinary bladder of the rabbit and mouse, in those of the peritoneum of man and the mouse, in the lacrymal and salivary glands. 2. *Free terminations of the nerve-fibres exist*, as in the so-called Pacinian bodies, in the heart and upon the mesenteric vessels of the frog. 3. *The thicker tubes of the sympathetic become at length attenuated, being converted into fine tubes*, as may be readily seen in the *rami intestinales*, *lienales*, and *hepatici*, although in the interior of the above-mentioned organs, these nerves may retain a few larger nerve-tubes, which, however, they eventually lose. The actual terminations of these nerves in the organs, in the heart, lungs, stomach, intestines, kidneys, spleen, liver, uterus, etc., are quite unknown; still, from the impossibility of finding dark-bordered tubes in the ultimate ramifications of these nerves, it may be supposed, that they end almost everywhere in *non-medullated, embryonic fibres*. In fact, I have hitherto in vain endeavoured to hit upon them.

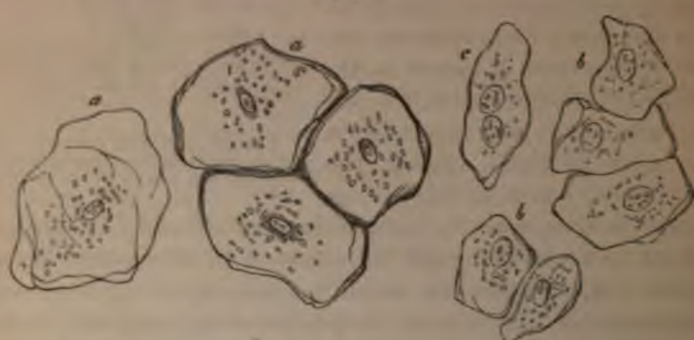
Quite recently *Remak* (l.c.) has given an entirely new exposition of the course of the fibres in the sympathetic, which is based upon the discovery made by him in 1837 of *multipolar cells* in sympathetic ganglia. According to *Remak*, the upper branch of each *ramus communicans*, which he calls *spinalis*, conducts to the sympathetic, fibres of the motor and sensitive roots of the spinal nerves, which, in the nearest ganglion, or in the subsequent one, become connected with the multipolar cells of the latter. From these same cells there then arise thicker and finer, dark-bordered, and also non-medullated fibres, which, partly by means of the lower branch of the *ramus communicans*, or the *ramus communicans sympatheticus*, join the spinal nerves to be distributed in the periphery, partly pass into the peripheral ramifications of the sympathetic itself, in which they become again connected (once or several times, according to the number of the peripheral ganglia), with multipolar cells, which on their part, give off, as might be expected, peripheral branches. According to this view, the sympathetic, therefore, contains no spinal nerve-fibres merely running along its trunk and branches and not uniting with its elements, and no fibres of its own running independently, but appears as an aggregate of many spinal nerves, whose elements are variously divided, and contain ganglionic cells at the places of division. By means of these cells, and the numerous tubes passing from them to the periphery, the independence of the sympathetic would be established and the increase of fibres accounted for; and doubtless, also, physiological explanations would be found to answer better than according to the hitherto received views of the structure of the sympathetic; only it is to be regretted that *Remak* has forgotten to adduce the proofs of his hypothesis, here shortly sketched, for the particulars of which my *Handbook* may be consulted, 2nd Edit. p. 354.

Development of the Elements of the Nervous System.

§ 125. The *nerve-cells,* wherever they occur, result merely from metamorphosis of the so-called embryonic cells; some simply enlarging, others growing out into a variable number of processes, and, in part at least, becoming connected with the nerve-fibres. Many nerve-cells appear at a later period to multiply by division; at least, I cannot otherwise explain the frequent occurrence of two nuclei in the nerve-cells of young animals, especially in the ganglia, and of cells connected by filaments of communication, which have been seen by different observers.

The *peripheral nerve-tubes* arise in the place which they are destined to occupy, but are further developed in such a manner, that the central ends are always more advanced in formation than the peripheral. With the exception of the nerve-terminations, the nerve-tubes are developed from fusiform nucleated cells, which are merely modifications of the primitive formative cells of the embryo, and which become connected to form pale, flat, long, nucleated tubes or fibres, 0·001‴ to 0·003‴ in breadth. The nerves at first membrane, agreeing more with the mucous layer of the epidermis, although, also, representing the horny layer. The relation of the cells from within outwards is the following:—Immediately upon the free surface of the mucous membrane, and upon the papillæ, are seated several layers of small vesicles, 0·004‴ to 0·005‴ in diameter (fig. 109), of which the deepest are almost invariably elongated and larger (0·006‴ to 0·009‴), and disposed perpendicularly to the mucous membrane. Then follow many layers of rounded, angular, flattened cells, which gradually increase in size and flatness from within outwards, and continually assume more and more of a polygonal form (fig. 110, *b*). Most externally, we

Fig. 110.



Epithelial cells in the oral cavity of man. *a*. Large; *b*. middle sized; *c*. the same with two nuclei. Magnified 350 times.

find some more layers of epithelial plates (fig. 110, *a*), as they are termed, which are gradually formed from the deeper cells; they are very large (0·02‴ to 0·036‴), rounded, angular scales, in which the process of flattening has so far advanced, that they can no longer be properly called vesicles.

All these cells have a thick cell-membrane, which is readily demonstrable by alkalies and acetic acid, and contain, according to the degree of flattening, a larger or smaller amount of clear contents, frequently with some fat-granules, and invariably a cell-nucleus. In the smallest cells, the nuclei measure 0·002‴ to 0·003‴, are elongated or round, and mostly without a distinct *nucleolus*; in the polygonal cells, there are invariably found one or two very beautiful, distinctly vesicular, mostly spherical *nuclei*, of 0·004‴ to 0·006‴ in size, with clear contents and one or two *nucleoli*. In the plates, finally, the nuclei enter upon a retrogressive process, have become smaller again, 0·004‴ to 0·005‴ in length, 0·002‴ to 0·0015‴ in breadth, are mostly flattened and more

1846, p. 102, tab. 6, 7), be traced with facility in the tail of the *larvæ* of the naked amphibia (fig. 107, 3; 108). Here we find, as the first rudiments of the nerves, pale branched fibres, 0·001‴ to 0·002‴ in diameter, which anastomose at certain places, and finally terminate in extremely fine fibrils, 0·0002‴ to 0·0004‴ in diameter. There is not the slightest difficulty in showing that these fibres arise by the coalescence of fusiform or stellated cells; for, firstly, we see such cells partly lying close to the fibres, but distinct from them, partly more or less connected with their off-shoots; and, secondly, we find, in the somewhat swollen places of division of the fibres, distinct cell-nuclei, and with them, at least in young larvæ, the well-known angular yelk granules, which originally fill all the cells of the embryo. At first the pale embryonic nerves are very few in number, and are limited to some short trunks lying close to the muscles of the tail; gradually, however, they are developed in a peripheral direction farther into the transparent parts of the tail, and in such a manner, that new cells continually become united with the nerve-trunks already present, whilst the latter unite with each other by means of slender off-shoots, almost like the capillaries of the same animal. These ramifications, when once formed, undergo further changes, as follows: Whilst the fibres gradually thicken to twice or four times their original diameter, dark-bordered fine primitive fibres are gradually developed in them, in the direction from the trunks to the branches, which, in no case, owe their origin to any newly superadded medullary sheaths, but are certainly formed only by the metamorphosis of a part of the contents of the pale fibres. The following relations, which have not hitherto been seen in the higher animals, are worthy of note: 1. The dark-bordered tubes scarcely ever entirely fill the pale fibres in which they arise, there being generally an interspace, often as wide as the fibres themselves, remaining between them and the sheath of the embryonic fibres, in which the nuclei of the primitive formative cells may occasionally be seen. 2. In the trunks and main branches, it is undoubted that several (2—4) dark-bordered tubes become developed within one and the same embryonic fibre; a very remarkable fact, proving the existence of dark-bordered tubes without structureless sheaths, and showing a correspondence with the muscular fasciculi, in which, likewise, many fine elements arise within one tube. Since the tails of tadpoles fall off at a subsequent period, unfortunately their interesting nerves cannot be followed to such a complete stage of development, as those of the dorsum of the tongue downwards to the part where the *genio-glossi* are lost in the lingual substance; it does not, however, end here with a sharp border, but is directly connected with the *perimysium* between the two *genio-glossi* muscles. At either side of this dissepiment, the *genio-glossi* spread out in a fan-shaped manner into the tongue (fig. 111), so that they occupy the middle of the organ from the apex to the root, and form a long, moderately broad, fleshy mass, which, however, is anything but compact. That is to say, the *genio-glossi*, arrived in the tongue itself, divide on either side, from the lower border of the lingual septum, where some of their bundles decussate, into a large number of *lamellæ*, lying behind each other, which, at short distances from each other, and separated by the transverse muscular fibres of the tongue, run to the dorsum; the most of them perpendicularly, but some of them curved forwards or backwards. The fibres of the *genio-glossus*, thus parted into separate laminæ, which are on an average 0·06‴ to 0·14‴ thick, extend as far the *septum linguæ*, and then alter their relation, and generally in such a manner, that they now form lamellæ extending from before backwards. Whilst previously, the *genio-glossi* were divided into transverse lamellæ by the separate layers of the *transversus*, they now become divided in the longitudinal direction, by the interposition of bundles of the upper longitudinal muscle of the tongue. These perpendicular and longitudinal laminæ are very distinct in the two anterior thirds of the tongue, less so in the region of the *papillæ circumvallatæ*, where especially in the middle of the tongue, the *genio-glossus* approaches the mucous membrane more in form of isolated fasciculi; lastly they are not all demonstrable at the root of the tongue. The *genio-glossus* terminates at the upper surface of the tongue, by its

Fig. 111.

Transverse section of the human tongue, a little in front of the *papillæ circumvallatæ*; *g. genio-glossus*; *l.i. longitudinalis inferior (lingualis)* with the *arteria ranina*; *tr. transversus*, visible in its whole extent on the right side, on the left only at the edge and between the divaricating bundles of the *genio-glossus*; *g.* termination of the *genio-glossus* upon the mucous membrane; *h.* termination of the *hyo-glossus*; *l.s. longitudinalis superior* with flat bundles interposed between the perpendicular fibres; *d.* glands of the margin of the tongue; *st. gl. stylo-glossus*.

bundles being continued in groups, immediately under the mucous membrane, into small tendinous stripes of connective tissue, which are then in part lost in the lower very firm layer of the mucous membrane, afterwards to be described, and in part run as far as the bases of the *papillæ*. At the root of the tongue, the *genio-glossus* does not extend as far as the mucous membrane, which can here be readily dissected with its mucous follicles from the deeper racemose glands, but ends upon and between the latter, connecting itself, here also by tendinous stripes, either to the glands or to a dense fibrous tissue lying between them; it also sends a small bundle to the *epiglottis* (*levator epiglottidis Morgagni*), perhaps also to the lesser *cornu* and body of the hyoid bone, and a second somewhat larger (*glosso-pharyngeus*) to the superior constrictor of the pharynx.

The *transverse muscle, i. e.*, the transverse fibres of the tongue, consists of very numerous lamellæ belonging separately to each half of the tongue, which dip in, very regularly, between the transverse laminæ of the *genio-glossus*, and are to be found in all parts of the tongue. Each lamella is 0·1‴ to 0·16‴ thick, in the middle of the tongue ¾ of an inch deep, being generally disposed perpendicularly, and its fibres extending from the *septum linguæ* to the lateral margin. These lamellæ might be said to begin directly from the surface of the septum in its entire depth, still they arise through means of a small quantity of tendinous tissue which is transversely arranged and distinguished from the longitudinal fibres of the septum, and, being united in the form of small, flat bundles, proceed, at first, directly outwards. In their further course they bend upwards, the uppermost, shortest fibres extending to the lateral parts of the dorsum, the lower, longer fibres reaching the proper border of the tongue, where they are likewise inserted into the mucous membrane by means of short bundles of connective tissue. The remaining lingual muscles form, in a certain measure, the investment of the tongue, and in their course, partly join the above-mentioned, partly pursue special directions.

The *hyo-glossus* (*basio-* and *cerato-glossus* of authors) presents nearly the same relations at the lateral parts of the tongue as the *genio-glossus* in the middle. That is to say, arrived at the lower surface of the lingual border, its thicker bundles divide into a larger number of thin transverse lamellæ, which, curving more or less upwards, slip in between the lamellæ of the transverse muscle, and in their further course present exactly the same arrangement as the *lamellæ* of the *genio-glossus*, to which they adjoin externally, except that, during the ascent to the dorsum of the tongue, their fibres proceed obliquely inwards, with a slightly curved course. At the dorsum of the tongue, the *hyo-glossus* lies between the *genio-glossus* and the upper border of the *transversus*, forms, like the former, longitudinal laminæ with perpendicularly arranged fibres, between which the fibres of the upper longitudinal muscle lie, and then, terminates likewise at the mucous membrane. This expansion of the *hyo-glossus* is thickest and most distinct in the middle of the tongue; posteriorly it becomes less distinct, in as much as the lamellæ of the *cerato-glossus* are here very delicate, and are also more horizontally arranged; still, even here, the lamellæ are interposed between those of the transverse muscle, and terminate at the dorsum of the tongue.

The *stylo-glossus* (fig. 118, *st, gl*) usually divides into two bundles, which present entirely different relations. The posterior smaller bundle proceeds directly inwards between the *cerato-glossus* and *basio-glossus*, and between the fasciculi of the latter, and penetrates in separate bundles between the lamellæ of the *lingualis* and *genio-glossus* as far as the *septum linguæ*, where at the same time it becomes attached to the fibres of the transverse muscle lying somewhat higher. The main part of the *stylo-glossus* runs inwards and downwards at the border of the tongue, is connected with the *lingualis inferior* in front of the *hyo-glossus*, and terminates in the mucous membrane of the lower surface near the tip of the tongue, and in that of the tip itself, the most anterior bundles of both muscles uniting in an arched manner.

The *lingualis* of authors, which I will call *lingualis* or *longitudinalis inferior* (fig. 118, *l i*), is a tolerably thick longitudinal bundle, situated between the *genio-glossus* and *hyo-glossus* at the lower surface of the tongue, whose commencement and termination cannot be readily ascertained. At first sight, the posterior part of the *lingualis inferior* appears to be lost in the form of numerous superimposed flat bundles between the transverse fibres of the *genio-glossus* (*glosso-pharyngeus*), the *stylo-glossus* and *transversus* at the root of the tongue; when more narrowly traced, however, it is seen that, like the most posterior parts of the *genio-glossus*, it divides into numerous laminæ, which ascend in a slightly arched manner between the transverse fibres as far as the outer part of the glandular layer of the root of the tongue, and then, like the lamellæ of the *genio-glossus* situated internally to them, terminates upon the latter. Anteriorly, the *lingualis inferior* is connected with the thicker fasciculi of the *stylo-glossus*, and ends with the latter at the tip of the tongue; but, joining the *hyo-glossus* anteriorly, it also proceeds in the form of numerous delicate lamellæ between the transverse as far as the dorsum of the tongue, in order, in short, to present the same relations at the border of the anterior third of the tongue, as the *hyo-glossus* further backwards.

Lastly, there exists in man also a *longitudinalis* or *lingualis superior* and independent *perpendicular fibres.* The *longitudinalis superior* (fig. 118, *l s*) exhibits a longitudinal layer of fibres situated between the uppermost fibres of the *transversus* and the mucous membrane, occupying the entire length and breadth of the tongue, and arising from the *chondro-glossus*, which has been incorrectly understood by most anatomists. The latter arises from the small horn of the hyoid bone as a moderately thick bundle, which is separated from the *basio-* and *cerato-glossus* by the lingual artery and the *glosso-pharyngeus*; it passes forwards beneath the deeper layer of glands of the root of the tongue, and in part through the midst of the terminations of the *genio-glossus* and *lingualis inferior;* occupies, somewhat in front of the *papillæ circumvallatæ*, almost the entire half of the tongue, and runs forwards immediately beneath the mucous membrane, between the extremities of the *genio-glossi* and *hyo-glossi* as far as the tip of the tongue, in the form of slender longitudinal laminæ, which are occasionally united with each other at acute angles, to be lost in the skin of the upper surface. Since these longitudinal fibres become thicker anteriorly, it is probable that they are joined by other independent superior fibres, which arise from, and terminate upon, the mucous membrane of the *dorsum*. I find *perpendicular fibres*, which do not arise from without, only in the apex, where they extend in form of delicate bundles between the upper and lower mucous membrane. The most anterior part of the *transversus* passes with its laminæ through the inner part of these bundles, whilst their extremities are pretty regularly traversed by the *longitudinalis superior* and *inferior* and *stylo-glossus,* so that, upon a transverse section, there appears an alternation of perpendicular and longitudinal fibres, similar to that which is represented in fig. 118, from the dorsum of the tongue.

It may still be mentioned, that the *glosso-palatinus* is partly lost in the mucous membrane of the lateral border of the tongue along with the *cerato-glossus,* and partly appears to join the larger bundles of the *stylo-glossus*.

If after this description of the several extrinsic, as well as intrinsic, muscles of the tongue, we cast a glance at the general structure of the organ, it is seen that the proper lingual substance possesses essentially only three orders of muscular fibres, which may be designated *perpendicular*, *transverse* and *longitudinal*. The *perpendicular fibres* come from the *genio-glossus* in the middle, from the *lingualis* and *hyo-glossus* laterally, at the apex also from the *perpendicularis*, and form, from the tip to the root, a large number of transverse lamellæ, occupying nearly the breadth of the two halves of the tongue, and whose fibres generally pass perpendicularly from the under surface to the upper. The *transverse fibres* of the *transversus*, and, in part, of the *stylo-glossus*, are interposed as somewhat thicker lamellæ between the above-mentioned, beginning at the septum and terminating at the lateral border and in part at the surface. Lastly, the *longitudinal fibres* belong to the *lingualis superior* (*chondro-glossus*), the *lingualis inferior* and *stylo-glossus*; they cover the upper surface, the border and part of the lower surface, and mostly lie immediately beneath the mucous membrane. The individual muscular layers of the tongue are invariably separated from each other by a thin *perimysium*, and partly, where larger vessels and nerves exist, by thicker layers of areolar tissue; in their interstices, moreover, they contain, in many places, a larger or smaller number of fat-cells, which accumulate in considerable numbers, especially between the *genio-glossi*, at the *septum*, at the root of the tongue, and beneath the mucous membrane.

Fig. 112.

A branch of primitive muscular fibre of 0·018''' from the tongue of the frog. Magnified 350 times.

In the tongue of the frog, there exist, as first described by *Dr. Waller*, very beautiful divisions of the transversely striped fibres (fig. 119). Although I have not been able to discover with certainty anything of the kind in the human tongue, still it has appeared to me occasionally, as if some of the fibres of the *genio-glossus* divide, shortly before their transition into the tendinous bands. The muscles of the tongue of the frog terminate in the mucous membrane and in the papillæ.

§ 131. The *mucous membrane* on the dorsum of the tongue, from the *foramen cæcum* to the tip, deviates from the remaining mucous membrane of the oral cavity in this respect, that it is very firmly connected with the muscular substance, and is covered with numerous prominences, the well-known *lingual* and *taste-papillæ*, the general form and arrangement of which are described in every anatomical work. Besides these prominent and obvious papillæ, there exist over all the gustatory region of the tongue other smaller ones, which are completely buried in the epithelium, and which entirely agree with those of the non-gustatory regions of the organ.

In its *intimate structure*, the part of the mucous membrane of the tongue which is destitute of prominent papillæ, agrees in all respects with that of the oral cavity generally, which has been already described.

With regard to the papillæ, the *papillæ filiformes* or *conicæ* (fig. 120) are conical, firm projections of the mucous membrane, pro-

Fig. 113.

Two papillæ filiformes of man, one with its epithelium magnified 35 times. After *Todd* and *Bowman*. *p*. the papillæ themselves; *a v*. arterial and venous vessels of one papilla, together with the capillary loops, which, however ought to enter the secondary papillæ.

vided with numerous elastic fibrils, and beset at the extremities only, or upon their entire surface, with a certain number (5 to 20) of smaller papillæ, 0·1‴ to 0·14‴ in length. The papilla is entirely covered by a tolerable thick coating of epithelium, which at the end splits up into a number of long and slender (0·01‴ to 0·02‴), sometimes sub-divided processes, with cornified cells, giving to the whole the appearance of a fine brush, and measuring up to 0·5‴, 0·6‴, 0·7‴ in length, and 0·02‴ to 0·028‴ in breadth at their bases. In each papilla, a small artery ramifies, and in such a manner, that each simple secondary papilla contains a capillary loop, from which a small venous vessel returns. The nerves, which are not always readily found, present one or two small trunks with from 5 to 10 dark-bordered primitive fibres of 0·002‴ to 0·003‴, which are withdrawn from view at the base of the simple papillæ, and terminate in a manner not as yet exactly ascertained.

The *papillæ fungiformes* are formed of a club-shaped process of the mucous membrane, which is thickly beset on its whole surface with simple conical papillæ of 0·1‴ to 0·12‴ in length, and covered by a simple epithelium, like that which occurs elsewhere in the oral cavity, and *without cornified cells and filiform processes*, which when measured from the apices of the papillæ, possesses a thickness of 0·04‴ to 0·05‴. The papilla contains much less elastic tissue than the *papillæ filiformes*, and the simple secondary papillæ contain scarcely any; but on the other hand, there is a very distinct mesh-work of connective tissue in bundles, 0·002‴ to 0·003‴ in diameter. The *vessels* present the same characters as in the *filiformes*, only they are much more numerous; and with regard to the *nerves*, one or two thicker trunks, 0·04‴ to 0·08‴, and several thinner filaments pass into each fungiform papilla, in which, branching in form of tufts and variously anastomosing, they finally separate from each other, and pass in all directions towards the simple secondary papillæ and their touch-bodies. The terminations of these nerves at the base of the simple papillæ measure only 0·001‴ to 0·0015‴, and they appear to end by means of free pale processes.

Fig. 114.

Papilla circumvallata of man in section. *A.* Proper papilla; *B.* wall; *a.* epithelium; *b.* secondary papillæ; *b b.* nerves of the papillæ and the wall. Magnified about 10 times.

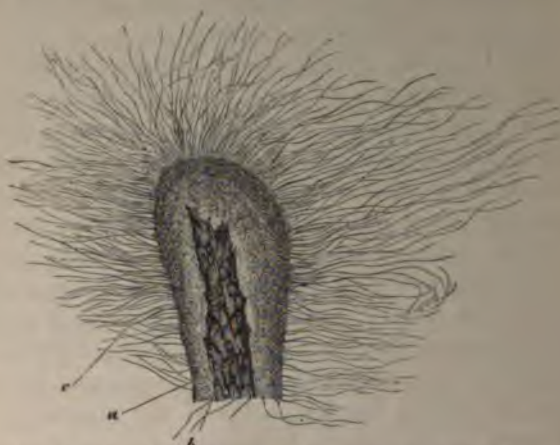
In the *papillæ circumvallatæ* (fig. 121), the papilla, which might be regarded as a fungiform papilla pressed flat, is closely beset on its flat terminal surface with simple conical secondary papillæ, and covered by an uniformly thick epithelial covering. The surrounding wall appears a simple elevation of the mucous membrane, and presents, beneath the epithelial covering on its summit, several series of simple conical papillæ. There is generally no elastic tissue in these papillæ; in other respects, they agree with the *fungiformes*, only they are still *richer in nerves*.

Each proper *papilla circumvallata* contains, in its lowermost parts, several nerve-trunks of 0·05‴ to 0·08‴ in diameter, which higher up are resolved into a very beautiful plexus, from which the nerves of the simple secondary papillæ proceed, radiating in all directions. The other conditions of the *circumvallatæ* are the same as in the *fungiformes*, only the nerve-tubes, even in the trunks, do not measure on an average more than 0·002‴, and scarcely more than 0·003‴, whilst at the bases of the papillæ they are only 0·001‴ to 0·0015‴ in diameter. In the walls surrounding these papillæ, there are likewise numerous nerves, of which the more intimate distribution appears to be quite the same as in the papillæ.

According to *Sappey*, the *lymphatics* of the tongue form a very dense net-work in the mucous membrane, especially of the upper surface, where they surround the individual papillæ, and even form a perfect net-work of delicate vessels in the papilla superficial to that of the blood-vessels.

The papillæ of the tongue exhibit manifold variations, among which the following are the most important: 1. *The papillæ filiformes may be all unusually long*, and furnished with epithelial processes of very considerable length. That condition of the tongue, which is commonly called 'coated,' chiefly depends upon the luxuriant growth of the epithelial processes of the *papillæ filiformes*, all of which, directed backwards, and apparently lying upon each other, form a special white covering. If the processes become still longer, so that the *papillæ filiformes* measure 1½‴ to 2‴, a *lingua hirsuta* or *villosa* is produced, which is likewise not unfrequently seen in different diseases, and can at length assume forms which make the tongue appear as if it were beset with hairs 4‴ to 6‴ long. 2. The *filiform papillæ may have very small epithelial processes or none at all*, and are scarcely distinguishable from the secondary papillæ of the smaller *fungiformes*. 3. The *filiform papillæ may not exist as special projections, but buried in the common epithelial covering of the dorsum of the tongue*. It occasionally happens, especially in old people, that the tongue, without being coated, presents at particular spots or over larger surfaces, no papillæ, but exhibits either a perfectly smooth surface, or only linear processes, which correspond to the usual rows of papillæ. Here the epithelium is more developed, and smaller papillæ, presenting more the usual form, lie deeply under it. In other instances, the tongue, even when the papillæ are properly developed, may present a smooth surface, caused by the papillæ being glued together by exuberant epithelium, mucus, blood, pus-corpuscles, ferment-fungi, mould, etc., which makes the surface perfectly smooth, or, perhaps, only more or less broken by cracks. 4. The *epithelial processes of the filiform papillæ are beset with fungi* (*Leptothrix buccalis, Robin*). Every microscopist is, probably, acquainted with brownish elongated (0·12‴ to 0·24‴ long, 0·04‴ to 0·08‴ broad) bodies (fig. 122) occurring on the

Fig. 115.



A collection of epithelial cells, *a*, covered by the granular matrix of the fungus, *b*, from which luxuriantly growing fungi (*c*) proceed. Magnified 350 times, from man.

coat of the tongue, and which consist of a dark axis and of a finely granular cortex. It is only the central part of this structure which is composed of cornified epithelial plates, which come from the epithelial processes of the filiform papillæ; the granular cortex, on the other hand, is nothing else than the matrix of a filiform fungus with filaments of only 0·0006‴ in breadth, which take root in it, often in enormous quantities.

Respecting the *physiology* of the papillæ of the tongue, the following may be gathered from the anatomical data given above. The filiform papillæ are neither organs of taste, nor fine organs of touch, since their thick, and what I am disposed to lay more stress upon, *cornified* epithelium is but little adapted to allow of the passage of fluids capable of being tasted, or to conduct other impressions to the scantily provided nerves, which extend only as far as the base of the simple papillæ. With *Todd* and *Bowman*, I consider the *filiformes* as allied in their functions to the tongue-spines of animals, which are merely modified *papillæ filiformes*, and am accordingly disposed to regard them as serving more or less for acting mechanically on the food, whilst their epithelium is a protective coating for the tongue.

The two other kinds of papillæ are subservient to the taste, and are, moreover, the seat of common sensation (for mechanical stimuli, heat and cold, etc.), for which functions they are excellently fitted by their thin, soft epithelium, the softness of the tissue of their papillæ, and the superficial position (in the secondary papillæ) and large number of their nerves. Microscopical ganglia occur on the branches of the *glosso-pharyngeus* and *lingualis* in the tongue, although it has not yet been ascertained whether they are concerned in the sensations of the tongue, or in the secretion of its glands.

OF THE GLANDS OF THE ORAL CAVITY.

1.—MUCOUS GLANDS.

§ 132. The mucous glands of the oral cavity are yellowish or whitish racemose glands, mostly of a rounded form, and with a botryoidal surface. They measure $\frac{1}{3}'''$ to $2'''$ in magnitude, and being generally situated immediately beneath or on the attached surface of the mucous membrane, open by short straight excretory ducts into the oral cavity, and furnish a mucous secretion. They present somewhat different characters according to situation, and are also designated with different names.

1. The *labial glands* lie between the muscular layer and the mucous membrane in large numbers; they are $\frac{1}{2}'''$ to $1\frac{1}{2}'''$ in size, and form around the opening of the mouth an almost continuous glandular ring, which begins at a distance of $3'''$ from the red border of the lip, and is about $\frac{1}{2}''$ in breadth.

2. The *buccal glands* are tolerably numerous but smaller, and are situated further outwards, covered by the *buccinator*. Some larger glands are found upon the *buccinator*, at the opening of the parotid duct, and still further backwards, in the region of the last molar tooth (*glandulæ molares*).

3. The *palatine glands*.—Those of the hard palate are smaller, and scarcely extend to the anterior half; whilst, on the contrary, the glands on the under side of the soft palate form a thick glandular layer, which is $3'''$ to $4'''$ thick anteriorly, but decreases somewhat towards the free border and the *uvula*. Glands are also present upon the posterior surface of the soft palate, but they are much smaller, and do not form a continuous layer.

4. The *glands of the tongue (glandulæ linguales)*—These I distinguish into—

a. The *mucous glands of the root*.—They partly form a very thick stratum of glands, of $\frac{1}{2}'''$ to $2'''$, situated beneath the simple mucous follicles of the root of the tongue, to be afterwards described, and the *papillæ circumvallatæ*. In the former situation, this glandular layer reaches a thickness of $4'''$, and extends almost continuously from one tonsil to the other. In front of the *foramen cæcum* these glands are smaller and more scanty, still a few are met with, even in front of the most anterior *papillæ circumvallatæ*, more or less deeply buried in the muscular substance, but never in the anterior half of the tongue. These glands are traversed by the terminations of the *genio-glossus*, and, in part, connected with them; the excretory ducts, which proceed from those situated posteriorly, are as much as 6‴ in length, and open partly on the surface, partly by funnel-shaped orifices, into the simple mucous follicles at the root of the tongue.

b. The *marginal glands of the root.*—Upon the borders of the root of the tongue there are found, on a level with the *papillæ circumvallatæ*, several of the before-mentioned perpendicular lamellated folds, and between them fine openings, which belong to a special smaller group of glands lying in the midst of the expansion of the *hyo-glossus* and *transversus*. In the mammalians, these glands, as also the folds in question (*Mayer's organ*), are frequently very much developed (see *Brühl*, l. c.).

c. The *glands of the tip.*—Upon the lower aspect of the tip of the tongue, on either side, and in the substance of the *lingualis inferior* and *stylo-glossus*, are two elongated groups of glands, 6‴ to 10‴ long, 2‴ to 3‴ thick, and 3‴ to 4‴ broad, whose excretory ducts, five to six in number, open upon peculiar fringed folds of mucous membrane parallel to the *frenum linguæ*. These glands were accurately described by *Blandin*, and were recently rescued from oblivion by *Nuhn*.

§ 133. *Intimate Structure of the Mucous Glands.*—All the above-mentioned glands entirely agree in all essential points of structure, and invariably consist of a certain number of lobules with a branched excretory duct. The lobules, which, in the simplest glands, amount only to some few (4 to 8), are elongated, pyriform, or sometimes rounded in outline, not unfrequently flattened, and measure 0·5‴ to 0·72‴ in length, and 0·2‴ to 0·48‴ in breadth, although they are occasionally almost quite round, and each is placed upon a branch (0·03‴ to 0·05‴ broad) of the excretory duct, which latter measures 0·12‴ to 0·3‴, or even 0·5‴ (glands of the root), in length. They consist of convoluted canals (fig. 123), beset with simple and compound vesicular dilatations, and appearing to be the immediate continuations of the excretory ducts of the lobules, which, on passing into the lobules, successively divide into a certain number of these canals, mostly without decreasing in diameter. What have been called *glandular vesicles (acini)*, are merely the dilatations and terminations of these canals, or ultimate branches of the excretory ducts. When viewed superficially, and with smaller magnifying powers, they all appear uniformly rounded or pear-shaped; but upon narrowly examining an entire lobule, or, still better, a gland which has been ijected and teased out, it is seen that their form is very various,

Fig. 116.

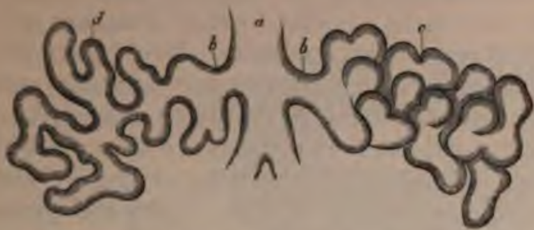


Diagram of two ducts of a lobule of a mucous gland. *a.* Excretory duct of the lobule; *b.* lateral branch; *c.* the *acini* of that branch *in situ*; *d.* the same spread out, and the duct displayed.

roundish, pyriform, or elongated. It is impossible to describe in detail all the forms which are met with, and I will, therefore, only further remark, that in point of appearance and structure, the terminations of the lobules are, for the most part, copies, as it were, on a small scale, of the seminal vesicles, as is represented in the annexed figure, which is, however, partly diagrammatical.

All the finest gland-ducts and vesicles, whose diameter varies from 0·02‴ to 0·08‴, consist of a special structureless envelope, the *membrana propria*, of 0·0008‴ to 0·0012‴ in thickness, and of a simple epithelium of polygonal cells (fig. 124), which very readily falls off, and then fills the *acini* in the form of a granular mass. The epithelial cells contain fluid mucus, which is coagulated by acetic acid (whence the cells become dark on the addition of that re-agent), and a certain number of fat and pigment-granules.

Fig. 117.

Two *acini* of a racemose mucous gland, of man; magnified 300 times. *a.* *Membrana propria*; *b.* epithelium, as it appears in the apparent section of a vesicle; *c.* the same seen from the surface.

The *excretory ducts of the lobules*, which, in the interior, are traversed by connective tissue as well as enveloped by it, possess an investment of connective tissue, with networks of fine elastic fibres, and a simple layer, 0·008‴ to 0·01‴ thick, of cylindrical cells. In the principal excretory ducts, the wall of the smallest glands, which are very rich in elastic tissue, measures 0·02‴; that of the larger, up to 0·03‴ and 0·04‴; while the epithelium is 0·01‴ to 0·012‴ in thickness. The glands are furnished with *numerous* small vessels, which penetrate, with the excretory ducts, or independently, between the lobules, and form in the interior a wide network of capillaries, 0·003‴ in diameter, surrounding the individual tubes and vesicles; so that, in every case, each of them is in contact with three to four capillaries. Nerves are met with in considerable abundance upon the excretory ducts, and occasionally, also, as moderately fine fibres, in the glands themselves.

The secretion of the racemose glands is a clear yellowish mucus, obviously coming from the epithelial cells, mingled accidentally with granules, nuclei, and remains of cells. It fills the excretory ducts and the other glandular spaces as far as the ultimate terminations, and even in these can be brought to view, on the addition of acetic acid, as a striated viscid substance. Mucous corpuscles, as they are termed, such as are found in the fluids of the mouth, are totally absent in the glands.

2.—FOLLICULAR GLANDS.

§ 134. The follicular glands of the oral cavity are 1, *simple follicles* at the root of the tongue; and 2, *compound*, on either side of the *isthmus faucium*, viz., the *tonsils*. In structure, these organs, whether simple or compound, are essentially alike, inasmuch as the tonsils may be regarded as being made up of simple follicular glands; on the other hand, they differ so widely from the mucous glands, that they cannot be ranked with them in any respect.

The simple follicular glands of the root of the tongue, extending as an almost continuous layer from the *papillæ vallatæ* to the *epiglottis*, and from one tonsil to the other, lie above the mucous glands of this region and immediately beneath the mucous membrane. Their position is so superficial, that the individual glands can be perceived as rounded elevations, and their number and arrangement recognised externally. On being dissected out, each follicle is found to be a lenticular or spherical body, of $\frac{1}{2}'''$ to $2'''$ in diameter, which, covered externally by the mucous membrane — here very thin — is loosely imbedded in the submucous tissue, and receives, at its lower surface, the excretory duct of a more deeply seated mucous gland. Every follicular gland presents in the centre of its free surface a punctiform opening, often rather wide ($\frac{1}{3}'''$ to $\frac{1}{2}'''$), and readily visible to the naked eye, which leads into an inverted-funnel-shaped cavity, characterised by its narrowness compared with the size of the follicle, and by its thick walls. The cavity is generally filled with a greyish mucous substance.

Each follicular gland (fig. 125) is a thick-walled capsule, which is surrounded externally by a fibrous investment, connected with the deep layers of the mucous membrane, and is lined internally by a continuation of the mucous membrane of the oral cavity with papillæ and epithelium. Between these two coats it contains, in a delicate, fibrous, vascular matrix, a certain number of large, completely shut capsules or follicles (fig. 125, *g*), which, being $\frac{1}{10}'''$ to $\frac{1}{4}'''$ in size, of a round or oblong form, and of a whitish colour, very much resemble the capsules of *Peyer's* and the solitary glands, and the vesicles of the spleen and of the lymphatic glands, and consist of a tolerably firm investment, 0·003''' thick, of a somewhat homogeneous connective tissue, without elastic fibres, inclosing greyish-white contents. On puncturing a follicle, its contained matter oozes out in form of a drop which is diffusible in water, and composed of a fluid-portion with solid particles. The former is present only in extremely small quantity, so that it appears as the connecting medium of the latter, which consist of cells, 0·003''' to 0·005''' in size, without any special characters. Acetic acid renders the cells granular and their contents whitish; it does not, however, precipitate any mucus, which proves that the contents of these follicles differ from mucus, but agree in nature with those of the spleen-corpuscles. The follicles are mostly so arranged as to form an almost continuous simple layer between the outer investment and the epithelium of the glands; but at particular parts we sometimes find, at least in the mammalians, two follicles in the thickness of the wall, close to or more widely separated from each other.

Fig. 118.

Follicular gland, from the root of the tongue of man. *a.* Epithelium lining the same; *b.* papillæ; *c.* outer surface of the gland, with the envelope of areolar tissue; *d. e.* cavity of the follicle; *f.* epithelium of the same; *g.* follicles in the thick wall of the gland. Magnified 30 times.

The vessels of the follicular glands are very numerous, and can often be readily traced in man, when filled with blood. Small arteries pass from without, through the fibrous investment, into the interior, where they ramify between the individual follicles in a beautiful arborescent manner, and terminate in the papillæ and also upon, and probably in, the follicles. The vessels of the papillæ present the same conditions as in the simple papillæ on other parts, and form either simple or compound loops; whilst upon the follicles and surrounding them there is an extremely beautiful and rich network of vessels, the finest of which, 0·004‴ to 0·006‴, running in an undulating manner immediately upon the coat of the capsule, form a moderately close meshwork. The veins collect themselves from the two places mentioned, and are very wide and numerous. According to *E. H. Weber*, lymphatics also appear to come from these glands, and I have observed nerves upon them.

According to my investigations, the tonsils are merely an aggregation of a certain number (10 to 20) of compound follicular glands, which, being firmly connected with each other, and held together by a common investment, form a large hemispherical organ, and also frequently coalesce by their orifices into a smaller number. Every section of the tonsil, however different the shape of its cavity and its external form, has quite the same structure. Tracing them from the oral cavity, we find that the epithelium passes into the recesses within the tonsil, and although somewhat attenuated, completely lines them as far as the ultimate accessory cavities. Beneath this epithelium there exists a greyish, soft, very vascular membrane, $\frac{1}{2}$‴ to $\frac{1}{3}$‴ in thickness; and external to this, another dense, relatively thick, fibrous investment, which, wherever two lobes or sections of the tonsils come in contact, belongs to them in common, and, outside of them, is connected with the common investment of the organ. The soft thick layer between the epithelium and the fibrous investment has the same composition as the corresponding layer of the follicular glands of the root of the tongue. Here also are seen, towards the epithelium, conical or filiform, or even slightly branched papillæ, 0·06‴ to 0·08‴ in length, and 0·01‴ to 0·03‴ in breadth; then, more deeply, there are rounded, completely closed follicles, situated close to each other, of the same size and with the same contents as those above described; lastly, a soft fibrous tissue connecting them together, and containing numerous vessels. The vessels are still more numerous than in the follicles of the tongue; but, on the whole, ramify in the same manner, only the papillæ frequently contain several loops, and the networks around the capsules are denser. Quite recently, I have, as I believe, observed vessels in the interior of the capsules, just as in *Peyer's* glands. The fibrous investment consists of connective tissue with elastic fibres, and receives some fibres of the superior constrictor of the pharynx. Nerves, it is true, are seen externally upon the tonsils and in the papillæ, still I have been no more successful in finding them, in the proper coat of the follicles, than in the follicles of the tongue.

The tonsils and the follicles of the tongue, agreeing as they do in structure, appear also to agree in the nature of their secretion; but it cannot be readily obtained pure from the former, because they also receive the ducts of mucous glands. It is a greyish-white matter, resembling mucus, which, however, as far as I can discover, contains no proper mucus, but consists of detached epithelium (plates), either alone or mingled with cells and nuclei, which entirely agree with those contained in the walls of the cavities of the follicles, and perhaps, come from burst follicles.

In inflammation of the tonsils, in man, it would appear that the follicles become swollen, their contents undergo alteration, and then they burst. The shut sacs, filled with purulent or cheesy matter, which are described in diseased states of the tonsils, may probably, when they do not exceed a certain size, be merely such altered follicles, and, by bursting, may furnish that secretion which collects in the larger cavities. Thus it so frequently happens, that the normal structure in the walls of the tonsils can no longer be recognised, and, at most, nothing is found but still open follicles, generally merely a granular substance, containing fibres and vessels, with remains of the papillæ and epithelium. In children, and in certain cases of slight hypertrophy, however, the follicles of the tonsils may be seen very beautifully. Of animals, the tonsils of the pig and sheep, and the tongue-follicles of the ox, are to be recommended as suited for examination; also the organs resembling tonsils, situated near to the entrance of the larynx in the pig, sheep, and ox, in which, when examined in the fresh condition, and when hardened in strong alcohol, the structure can be at all times and easily discovered.

The greyish, yellowish, or greenish, sometimes softer, sometimes more consistent material, which is so frequently met with in the cavities of the tonsils as a somewhat abnormal occurrence, contains larger and smaller cells with single nuclei, which have, in part, undergone the fatty degeneration, and which sometimes present hollow spaces in their interior and thickenings of their membranes; further, epithelium, and occasionally crystals of cholesterine and filiform fungi. The secretion may be regarded as more normal when it consists only of epithelium, of small cells destitute of fat, and of free nuclei; the latter two elements being quite the same as those in the follicles. Still we frequently find such a considerable quantity of this secretion, as to suggest the occurrence of an excessive cell-formation and rupture of the follicles.

The signification of the follicles of the tonsils and of the follicles of the tongue (to which all that has been above remarked equally applies), is, in any case, ambiguous. If they do not burst normally from time to time, which is very improbable, they could, as far as regards their secretion, only be of use by elaborating a fluid in their interior, which subsequently finds its way into the hollow spaces of the glands. Moreover, the resemblance of the follicles in question, with those of the solitary and especially of *Peyer's glands*, as well as with those of the spleen and lymphatic glands, leads us to enquire whether they are not to be ranked with those organs. At any rate, it ought not to be forgotten that these follicular glands also undoubtedly secrete, and that, accordingly, the comparison of them with lymphatic glands (*Brücke*) can certainly not be carried out in all points. The solitary follicles of the large intestine, from which a secretion obviously takes place into the depression situated over them, have, in my opinion, the nearest resemblance to the follicles in question, also the patches of *Peyer*, which I place in the same rank.

3.—SALIVARY GLANDS.

§ 135. The *Salivary Glands*, *i. e.*, the *parotis*, *submaxillaris*, *sublingualis*, and the glands of *Rivini*, agree so fully in their structure with the racemose mucous glands, that a detailed description of them would be superfluous. They are compound racemose glands, and may be considered anatomically as aggregations of numerous mucous glands; that is to say, the lobules of the first and second order correspond, the latter to the entire mucous glands, the former to single lobules of them. The lobules of the second order then unite to form still larger divisions, and a certain number of the latter form the entire gland. The excretory ducts, corresponding in number to the divisions of the gland, are more or less branched, and ultimately present the same conditions at their extremities as those of the mucous glands.

In *intimate composition*, likewise, the salivary glands offer little worthy of remark. The *acini*, in all the three kinds of glands, uniformly measure 0·016‴ to 0·024‴, or 0·03‴ in diameter, are as variously shaped as in the mucous glands, and arise in a similar manner from the ducts. Their *membrana propria* is frequently double-contoured, and always covered internally with a pavement epithelium, whose cells, which have but one nucleus, and are 0·005‴ to 0·008‴ in size, can be obtained in beautiful series by squeezing a gland. In the submaxillary and sublingual glands, these cells constantly contain mucus, also a large number of fat-granules and sometimes pigment-granules; whilst in those of the parotid the mucus is absent, and even the granular formations are less frequent. In the former, acetic acid renders the contents of the cells turbid, and does not clear them up when added in excess, on which account it cannot be recommended for their investigation, but rather diluted caustic soda, which allows the epithelial cells to be seen *in situ*.

The *excretory ducts* of the salivary glands are lined by a simple layer of cylindrical epithelium, whose cells measure up to 0·016‴

in length; the remaining part of the wall consists of connective tissue, with numerous, very dense networks of fine and thicker elastic fibres, to which, in the submaxillary duct, a thin layer of *smooth muscular fibres* is superadded. The vessels present the same conditions as in the mucous glands.

Nerves pass from the *plexus caroticus externus*, with the vessels, into the interior of the glands, where they are met with in small numbers upon the vessels, excretory ducts, and other parts, and appear to end with free extremities. Besides, the submaxillary ganglion (*lingualis* and *chorda tympani*) supplies the two smaller pairs of glands; and the facial nerve, and, probably, the *auricularis anterior* supply the parotid.

The secretion of the salivary glands is, normally, destitute of definitely formed constituents, but may accidentally contain cylindrical cells of the excretory ducts, or half-decomposed cells from the *acini*. Its physical and chemical properties are different in the different salivary glands. The *saliva of the parotis* is clear and fluid, and, like the *acini* themselves, contains no mucus. The secretion of the *submaxillaris*, on the other hand, contains mucus and is ropy; and, according to *Bernard*, a watery extract of the gland likewise yields mucus. The *sublingualis* contains still more mucus. Hence the salivary glands, with the exception of the parotis, are very closely related to the mucous glands of the oral cavity, and, at any rate, there is nothing to warrant a decided separation of the glands in question.

This is the proper place to make a few remarks on the *salivary or mucous corpuscles* of authors. These are roundish cells, 0·005‴ in size, with one or several nuclei, which, so to speak, are constantly found in the fluids of the mouth, although in very various quantities, and which are looked upon by most authors as coming from the mucous or salivary glands, but incorrectly; since the examination of both kinds of glands, and of their excretory ducts, shows that they do not secrete any definitely formed constituents. The mucous corpuscles are, in my opinion, merely products of the mucous membrane of the oral cavity; and, indeed, although almost constant, still not altogether normal, but a kind of exsudation of pus-corpuscles, with which, also, they are acknowledged to have the greatest resemblance in their structure. Their origin is still unknown, yet it is most probable that they come, in some way or another, from the epithelium.

For the *investigation* of the mucous membrane of the oral cavity, perpendicular sections of fresh or dried pieces, or such as have been hardened in absolute alcohol, are especially necessary. In these the papillæ and epithelium are very distinct, and become still more clear on the addition of very diluted caustic soda, when the deepest epithelial cells also readily come into view. The papillæ are to be studied in macerated pieces, or when it concerns only their position and form, in perpendicular or horizontal sections, treated with concentrated caustic potash, which detaches the epithelium. The papillæ of the tongue, whose epithelium, especially in the *filiformes*, is frequently not found entire, are to be treated exactly in the same manner. The nerves of all these parts are best seen on the addition of diluted caustic soda; acetic acid also frequently serves for this purpose. The muscles of the tongue are to be investigated by minute dissection, and the arrangement of fibres may be tolerably well made out by this means in half macerated tongues, which have lain for a long time in alcohol. Fresh tongues may also be employed, but they are not nearly so well fitted for the purpose, and it is generally necessary to boil them until they are quite soft. In order to obtain sections for the microscope, the tongue may be dried or hardened in alcohol, or hard boiled. In all these three cases caustic soda is useful for giving clearness, although it somewhat attacks the muscular fibres. Perpendicular, longitudinal, and transverse sections in various directions, are to be recommended, especially through the glandular region. Concerning the investigation of the glands, we have already mentioned what is most important.

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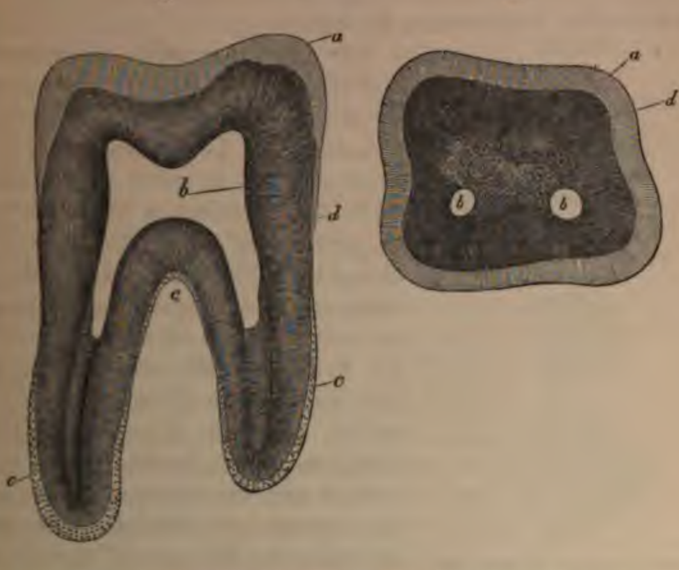
OF THE TEETH.

§ 136. The teeth (*dentes*) are hard organs implanted in the alveolar processes of the jaws, which, although in some points quite the same in structure as the bones, in others closely related to them, yet must, in respect of their development, be regarded as pertaining to the mucous membrane.

In every tooth we distinguish the *proper tooth* and the *soft structures*. The former is divided into a free part, the *crown (corona)*, and an imbedded portion, the simple or divided fang or root *(radix)*, whose various forms will be found described in the text-books of anatomy. In its interior is a small cavity, the *cavity of the tooth (cavum dentis)*, *pulp-cavity*, which, prolonged in form

a canal *(canalis dentalis)*, even extends into the fangs, and ter-
nates at the apex of each with a fine, usually simple, rarely
able *(Havers, Raschkow)* aperture. To the soft parts belong,
t, the gum *(gingiva)*, a hard substance, composed of the mucous
mbrane and the periosteum of the jaws, which surrounds the
ver half of the crown or the neck of the tooth, *collum*; secondly,

Fig. 119.



Human molar tooth; magnified about five times. A. a longitudinal, B. a transverse section. *a*. Enamel; *b*. pulp-cavity; *c*. cement; *d*. dentine, with the canaliculi.

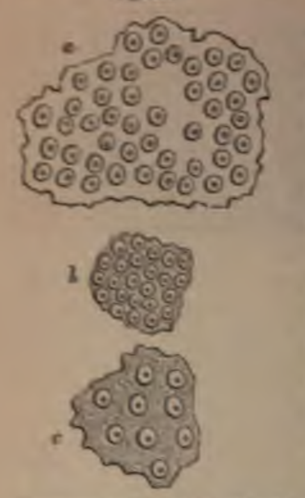
periosteum of the alveolar cavity, which connects the tooth
y firmly with the *alveolus*; lastly, the *dental pulp (pulpa dentis)*,
oft substance rich in vessels and nerves, which fills the cavity of
tooth, and which is connected by the aperture or apertures in
root with the above-mentioned *periosteum*.

The *proper tooth* (fig. 119) consists of three different tissues: 1.
dentine, which constitutes the chief portion of the tooth, and
ermines its general form; 2. the *enamel*, which forms a tolerably
ck covering upon the crown; and 3. the *cement*, which covers
fang externally.

§ 137. The *dentine, ivory, substantia eburnea, ebur* (fig. 119, *d*),
yellowish-white in aspect, and in thin sections of fresh tooth,

appears translucent or transparent. In the dry state it is white, with a satiny or silky lustre from the entrance of air into a special system of canals, which pervades the substance. The dentine is considerably harder and more brittle than the bones and the cement, but much less so than the enamel. It alone bounds the *pulp cavity*, with the exception of a small place at the root, and is never actually seen outwardly in uninjured teeth, for even at the neck of the tooth it is covered by enamel, although in a thin layer, and where the latter ceases, by cement.

Fig. 120.



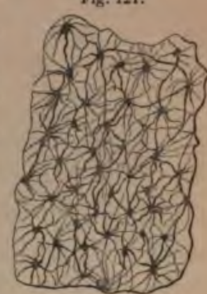
Transverse section of dentinal canals, as they are usually seen. *a*. Ordinary distance apart; *b*. more crowded; *c*. another view. Human molar. Magnified 400 times.

The dentine consists of a *matrix*, and of numerous tubules running in it, the *dentinal tubules, dental canals, canaliculi dentium*. The *matrix*, even in the finest section, is quite homogeneous, without presenting a trace of being constructed of cells, fibres, or other elements. The dentinal canals (fig. 120), are microscopical tubes 0·0006‴ to 0·001‴, some of them 0·002‴ (at the root) in width, which begin with free openings on the wall of the pulp-cavity, and run through the entire thickness of the dentine as far as the enamel and the cement. Each canal has a special wall, which is less in thickness than the diameter of the channel, and can be recognised in transversely cut canals, although not always even here, as a small yellowish ring around the cavity; in a longitudinal section, it is almost entirely withdrawn from view. During life, the canals contain clear, perfectly fluid contents, and are, accordingly, not so readily visible in fresh preparations; it is different in dry sections, when they are filled with air, and the individual tubes appear as black lines when viewed by transmitted, and as shining filaments by reflected light. In consequence of the very large number of the canals, which in many places is so considerable, that their walls are almost in contact, dry sections appear milk-white, and, if they are not very thin, are quite unfit for microscopical examination, except when the air has been driven out of the canals by the addition of some pellucid and not too viscid fluid.

The course of the dentinal canals is not straight, but *undulating*; besides, they exhibit numerous *ramifications* and *anastomoses*.

Each canal usually describes two or three *large curves*, and a very large number (up to 200 in a line, *Retzius*) of *small flexures*. The ramifications of the canals appear as divisions, and also as true ramifications. The former are very frequently met with near to the origin of the tubes from the dental cavity, and are almost always bifurcations, which are repeated two to five times or more, so that at length, four, eight, sixteen, or more canals arise from a single one. The canals, now narrower after their division, run close together, and nearly parallel towards the surface of the dentine, and, except in the fang, first begin to send out ramifications in the outer half or in the outer third of their course. These ramifications appear in the fangs chiefly as fine branches issuing from the main tubes, but in the crown as bifurcated terminations of them. In the latter case they are for the most part few in number; it is otherwise on the fang, where the branches, being generally close to each other, and passing off from the canals at right or acute angles, give them sometimes the appearance of a feather, sometimes of a brush; the latter especially, when the branches are longer and ramify still more. The *terminations* of the dental tubes are more or less fine according to the number of their ramifications, and are frequently so very fine, that they appear as extremely delicate, pale lines, like fibrils of connective tissue, and are, at length, withdrawn from view. Wherever the terminations are distinct they either reach the surface of the dentine, where they partly end in a granular layer, to be afterwards described, or pass into the innermost parts of the enamel and cement; or they join together in pairs in the form of loops in the dentine itself (*terminal loops of the dentinal canals*). The *branches* of the main canals are almost always very fine, mostly simple, but sometimes branched, and, as can be best demonstrated in the fangs, where they are unusually numerous, serve to connect neighbouring or more remote canals, by anastomoses in form either of transverse branches or of loops. The final terminations present the same conditions as the bifurcated or simple terminations of the main canals, and end either free or with loops in the dentine, or extend beyond the latter.

Fig. 121.



Transverse section through the dentinal canals of the fang, in order to show their extremely numerous anastomoses. Magnified 350 times. Of man.

According to *Von Bibra,* the chemical composition of dry dentine is the following:—

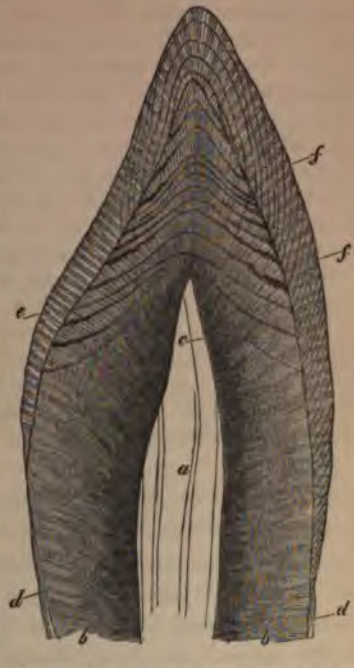
	Molar Tooth of a Man.
Phosphate of Lime and some Fluoride of Calcium	66·72
Carbonate of Lime	3·36
Phosphate of Magnesia	1·08
Salts	0·83
Cartilage	27·61
Fat	0·40
	100·00
Organic Substances	28·01
Inorganic Substances	71·99

According to *Tomes,* fresh teeth, after the removal of the pulp, lose $\frac{1}{8}$ to $\frac{1}{17}$ of their weight when dried. The organic basis of the teeth, which may be readily obtained by treating them with hydrochloric acid, is quite identical with that of the bones, and is readily convertible into gelatine by boiling. This *tooth-cartilage,* as it is termed, completely retains the form of the dentine, and, except that the tubes are with difficulty visible, even its internal structure. If it be macerated in acids or alkalies until it is quite soft, the matrix is found in the act of disintegration, but *the dentinal tubes, with their walls, are still preserved, and may be isolated in large quantities* (see my *Micr. Anat.* ii. 2, p.61, fig. 189). When still longer macerated, everything is dissolved. The dentinal tubes may be also isolated after long continued boiling of the tooth-cartilage. When a tooth is exposed to a red heat, the inorganic parts remain behind, and retain the form of the tooth, just as when it is treated with caustic alkalies. The dentine, accordingly, like the bones, with which it agrees so very much in its chemical composition, is made up of an intimate mixture of organic and inorganic parts.

The apparent walls of the dentinal tubes, which are usually seen upon the transverse sections (fig. 120), are not the true walls of the canals, but rings, the appearance of which arises from this, that a certain length of the canals is always seen with the microscope in the thickness of the section, never sufficiently fine to obviate this effect, and the short tubular segments being curved in direction, a greater apparent thickness is thus given to the walls than they really possess. If, upon a transverse section, the openings of the canals be brought accurately into focus, we perceive, instead of a dark ring, only a yellowish, very narrow edge, and it is this that I regard as being the true wall.

The dentine not unfrequently presents indications of a lamellation, which, in longitudinal sections, appears in the form of arched lines (fig. 122), coursing more or less parallel to the circumference of the crown, and varying in distance from each other, though sometimes close together; in transverse sections they appear as rings, and are especially distinct in the crown. These *contour-lines*, as they are called by *Owen*, are the expression of the stratified depositions of the dentine. In animals, they are occasionally very beautiful, particularly in the *Cetacea* and *Pachydermata* (*Zeuglodon*, *Dugong*, *Elephant*), and also in the *Walrus*. Here, as also in fossil teeth, a breaking up of the ivory into lamellæ (*Owen*) is very frequently observed, indications of which are also found in fresh human teeth, and in tooth-cartilage.

Fig. 122.



Perpendicular section of the crown of an incisor; magnified 7 times. *a*. Pulp-cavity; *b*. dentine; *c*. arcuate contour lines, with interglobular spaces; *d*. cement; *e*. enamel with indication of the course of the fibres in different directions; *ff*. colour lines of the enamel. From man.

At the crown, the dental canals not unfrequently pass for some distance into the enamel, and occasionally enlarge so as to form wider cavities (fig. 125), which, perhaps, are to be regarded as being more of a pathological nature. Similar not quite normal formations are the *interglobular* spaces in the dentine itself. *Czermak* designates with this name very irregular cavities, which are bounded by spherical projections of the dentine, and which are situated at the extremities of the contour-lines. The spaces themselves are sometimes very large, traversing numerous dentinal canals, and interrupting them in their course, sometimes very small, so that only some very few tubes are involved by them. In the former case, their boundaries are distinctly visible as spherical projections, of 0·002‴ to 0·012‴ and more, which, being penetrated by dentinal canals, and presenting quite the same appearance as the dentine, are obviously merely portions of that substance, whilst in the latter, these *dentine-globules*, as I will call them, are not always distinct. This holds good especially for the smallest spaces, which, on account of their jagged figure, and from the circumstance that the dentinal canals are intimately connected with them, might be held for bone-corpuscles in the dentine, and have been so considered; still, even in these, we are almost always able, at least in the crown, to recognise their agreement with the larger spaces. This is more difficult in the fangs, where smaller interglobular spaces and globules form a granular layer (*Tomes*), which frequently looks like a layer of small *lacunæ* or simple granules. In the normal dentine, I have but rarely observed true *lacunæ*, and always only at the cement-boundary; on the other hand, interglobular spaces and dentine globules also occur in the interior of the dentine of the fangs, and are especially beautiful upon the walls of the pulp-cavity; in which latter place the globules frequently produce inequalities visible to the naked eye, or even stalactitic formations. The interglobular spaces, which are normal in the developing tooth, contain, during life, no fluid, as might be believed at first sight, but a soft substance with tubes, agreeing with the tooth-cartilage, and formed exactly like dentine, and which, strange as it may appear, offers more resistance to hydrochloric acid than the matrix of the true ossified tooth, and on this account can be isolated exactly like the dentinal tubes. In sections, this 'interglobular substance' generally dries up in such a manner, that a cavity arises which admits air, and it is only then that we can properly speak of interglobular spaces. Many teeth exhibit, it is true, no interglobular substance, but here and there the outlines of dentine-globules in the form of delicate arched lines (*Owen's* dentinal cells).

Dentine with Haversian canals, or *vaso-dentine*, as it is called by *Owen*, such as occurs in many animals, is very rarely met with in man, and I only know of one case, which was observed by *Tomes* (l. c.), in which the vascular canals were somewhat numerous; on the other hand, we occasionally see in the dentine, which is formed in cases of obliteration of the pulp-cavity, along with more irregular dentinal tubes, a few Haversian canals and rounded cavities, which look like bone-corpuscles, the *osteo-dentine of Owen*, as it is called.

§ 138. The *enamel, substantia vitrea* covers the crown of the tooth as a connected layer, is thickest upon and in the neighbourhood of the masticating surface, and gradually decreases towards the fangs, till, at last, it terminates in a thin, sometimes sharp, sometimes slightly indented border. It terminates earlier upon the surfaces of the crowns which are directed towards each other, and extends further downwards upon the inner and outer sides. The external surface of the enamel appears smooth, but almost always possesses delicate, closely approximated, transverse ridges, along with which well pronounced annular swellings may also occur. A delicate pellicle, which was discovered by *Nasmyth*, and which I will call the *cuticle of the enamel*, covers it entirely, but is so intimately connected with the enamel, that it can only be demonstrated by the employment of hydrochloric acid. The enamel is bluish, in thin sections, translucent, much more brittle and hard than the other substances of the tooth, so that it can scarcely be penetrated by the knife, and emits sparks when struck with steel (*Nasmyth*). In chemical composition, it may be compared to an osseous substance, containing a minimum of organic matter; but the organic constituent does not belong to the gelatinous tissues, and differs in no respect from the substance of the epithelium. It contains, according to *Bibra*—

	Molar Tooth of an Adult Man.
Phosphate of Lime, with some Fluoride of Calcium	89·82
Carbonate of Lime	4·37
Phosphate of Magnesia	1·34
Salts	0·88
Organic Substance	3·39
Fat	0·20
	100·00
Organic Substance	3·59
Inorganic parts	96·41

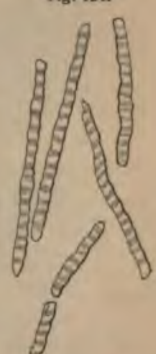
The enamel, as is even indicated by its fibrous cleavage, consists throughout of the so-called *enamel-fibres* or *enamel-prisms* (fig. 123). These are mostly pentagonal or hexagonal (although not quite regular) solid, long prisms, 0·0015‴ to 0·0022‴ in breadth, which, in general, extend through the entire thickness of the enamel, and rest, with one extremity, upon the dentine, and with the other, upon the cuticle of the enamel. In the teeth of adults, these fibres can be very readily seen in transverse and longitudinal views, but can scarcely be isolated for any great length; it is otherwise in young teeth, or in such as are in the process of development, where the enamel is much softer, and can be cut with a knife.

Fig. 123.

Surface of the enamel, with the extremities of the enamel-fibres; magnified 350 times. Of the calf.

Upon isolated prisms thus obtained, whose broken extremities may, perchance, be pointed, whence also called *enamel-needles*, the surfaces and borders can, in part, be very distinctly recognised, and besides, especially after the addition of somewhat diluted hydrochloric acid, more or less distinct transverse striæ, arising from slight varicosities, and disposed in linear series at distances of 0·0014‴ to 0·002‴, which give the fibres a certain resemblance to muscular fibres, or rather to colossal muscular fibrillæ, and, at any rate, are the expression of their growth through apposition, or are *not* the expression of their composition of cellules. If the hydrochloric acid be allowed to act more strongly, the fibres soon become quite pale, the transverse striation disappears, and there remains nothing behind but a delicate framework of the former solid fibres, which also, at length, breaks down. Thus, in teeth which have been treated with hydrochloric acid, almost nothing of the enamel remains behind; and the latter does not, like the decalcified dentine, preserve its form.

Fig. 124.



Fragments of enamel-fibres, isolated after very slight action of hydrochloric acid; magnified 350 times. Of man.

The conjunction of the enamel-fibres is effected without any visible intermediate substance, and is very intimate. I have not, hitherto, been able to convince myself that canals regularly exist between the enamel-fibres; still there are, doubtless, not unfrequently cavities of various kinds in the enamel. Among these I reckon, 1, the above-mentioned continuations of the dentinal canals into the enamel, and the elongated cavities upon the boundary of the dentine, occasioned by the enlargement of these canals (fig. 125, *c*); and 2, breaches in form of fissures in the middle and outer parts of the enamel (fig. 125, *b*). The latter are not connected with the former, are never entirely absent, and frequently exist in exceedingly large numbers, as narrower or wider fissures, which, however, are never filled with air.

Fig. 125.

Human dentine and enamel; magnified 350 times. *a*. *Enamel-cuticle*; *b*. enamel-fibres, with fissures between them and transverse lines; *c*. large cavities in the enamel; *d*. dentine.

The *course* of the enamel-fibres is, in general, the same as that of the dentinal canals of the crown, although larger curvatures occur in them only upon the masticating surface. All the enamel-prisms, moreover, do not appear to extend through the entire thickness of the enamel, although this is certainly the case with the majority. Peculiar, also, are the *decussations* of the enamel-prisms, which take place in transverse planes of the tooth in such a manner that not separate fibres, but entire band-shaped layers of them (corresponding to fine, externally visible circular lines, 0·08‴ to 0·12‴ in thickness), extend in very various directions (each layer preserving the same direction), from the dentine as far as the outer surface of the enamel; which arrangement gives to perpendicular sections, especially after they are moistened with hydrochloric acid, a peculiar striated appearance (fig. 122), inasmuch as when so treated, alternate darker transverse sections, and lighter longitudinal aspects of the prisms come to view. Such decussations constantly occur, also, upon the masticating surface, and layers of enamel run here generally in an annular form, so that upon the molars they describe circles, and upon the cutting teeth ellipses; but towards the middle of the masticating surface, irregularities of these lines occur, which cannot, as yet, be clearly made out. To be distinguished from the colourless striæ, which indicate the above-described stratified arrangement of the enamel-fibres, are certain *brownish lines* or *colourless striæ*, which cross the fibres in various directions, and which, on perpendicular sections, appear as obliquely ascending lines or arches (fig. 122); on transverse sections, as circles on the outer layers of the enamel, rarely throughout the entire enamel — lines, which I regard as being the expression of the lamellated mode of formation of the enamel.

The cuticle of the enamel is a calcified, structureless membrane, 0·0004‴ to 0·0008‴ thick, which, upon the surface directed towards the enamel, is furnished with small depressions for the reception of the extremities of the enamel-fibres, and, from its great capability of resisting chemical re-agents, forms an excellent protection for the crown of the tooth.

§ 139. The *cement, substantia ostoidea* (fig. 119, A, *c*), is a cortex of true osseous substance, which covers the fangs of the teeth, and in many-fanged teeth, not unfrequently cements them together. It commences as a very thin layer where the enamel ceases, either simply bordering upon, or extending for a small distance over the latter, becomes thicker as it descends, and, finally, attains its greatest thickness upon the ends of the fangs, and upon the alveolar surfaces of the molar teeth between the fangs. In man, its inner surface is very intimately connected with the dentine, without any intermediate substance, so that very frequently, at least with higher magnifying powers, the boundary of the two is not very sharp. The outer surface is very closely surrounded by the periosteum of the alveoli, less firmly by the gum, and, after detachment of these soft parts, is mostly uneven, often circularly striated. The cement is the least hard of the three substances of the teeth, and is almost, chemically, the same as the bones. *Bibra* found —

	In Man.	In the Ox.
Organic Substance	29·42	32·24
Inorganic Substance	70·58	67·76
	100·00	100·00

In the ox, the proportions of the several ingredients were —

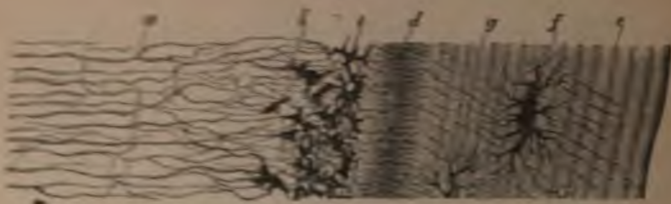
Phosphate of Lime and Fluoride of Calcium	58·73
Carbonate of Lime	7·22
Phosphate of Magnesia	0·99
Salts	0·82
Cartilage	31·31
Fat	0·93
	100·00

The cement is readily deprived of its earthy salts by acids, and a white cartilage remains behind, which is readily separable from the dentine, and furnishes, when boiled, ordinary gelatine.

The cement, like the bones, consists of a *basal substance*, or *matrix*, and *lacunæ*, but only seldom contains *Haversian canals* and vessels. Besides, we frequently meet with special canals, similar to those of the dentine, and with other more abnormal cavities.

The basal substance is sometimes granular, sometimes striated in the transverse direction, sometimes more amorphous, frequently lamellated like the bones. The lacunæ possess all the essential characters of those of the bones, so that a detailed description of

Fig. 126.



Dentine and cement, from the middle of the fang of an incisor tooth. *a*. Dentinal tube; *b*. interglobular spaces, looking like lacunæ; *c*. finer interglobular spaces; *d*. commencement of the cement, with numerous closely-disposed canals; *e*. lamellæ of the same; *f*. lacunæ; *g*. canaliculi. Magnified 350 times. Of man.

them may be omitted. Their only peculiarities are their very variable number, form, and size (0·005‴ to 0·02‴, even 0·03‴ in diameter), and the unusual number and length (up to 0·03‴) of their processes. These often appear in the form of plumules and pencils, and serve, when the lacunæ are not isolated, both to connect these cavities with each other, and to form anastomoses with the extremities of the dentinal canals. In the thinnest part of the cement, towards the crown, the lacunæ are always entirely wanting. They generally begin to appear towards the middle of the fang; are, however, at first, few and isolated, but become more and more numerous towards the extremity, and then not unfrequently lie very regularly in series in the cement, just as in the outer layers of the cylindrical bones. The most of their processes are directed outwards and inwards, which occasions an uniform fine transverse striation of the cement.

The thick layers of cement of old teeth possess large numbers of *lacunæ*, but they are, for the most part, very irregular, and have especially an elongated form. Many *lacunæ*, either separately or in groups, are half or entirely surrounded by very distinct clear yellowish, slightly sinuous borders, which, perhaps, are in some way related to the cells from which the *lacunæ* are formed. In young teeth, Haversian canals do not occur in the normally thick cement; they are, however, quite common in old teeth, particularly in the molars and in hyperostoses of the teeth. They penetrate from without into the cement, ramify two to three times, and then terminate in blind extremities. Their width is too small (0·003‴ to 0·01‴) to contain marrow in addition to the blood-vessels, and they are usually surrounded by some concentric lamellæ, as in the bones.

Besides the above spaces, the cement occasionally contains other peculiar sinuous cavities, which are certainly of a pathological nature (see my *Micr. Anat.* ii. 2, p. 82, fig. 202); frequently also canals like dentinal canals (fig. 127), which are sometimes close together, sometimes more isolated, occasionally with branches, which are frequently connected with the terminations of the dentinal canals and the processes of the *lacunæ*.

Fig. 127.

Cement and dentine of the fang of an old human tooth. *a.* dental cavity; *b.* dentine; *c.* cement with lacunæ; *e.* Haversian canals.

§ 140. The *soft parts* of the teeth comprehend the *periosteum of the alveoli*, the *tooth-pulp*, and the *gums*. The *periosteum* of the alveoli is very accurately applied to the surface of the fangs, and agrees in structure with the periosteum of other parts, except that it is softer, and contains no elastic elements, but rich plexuses of nerves having numerous thick nerve-tubes.

The *tooth-pulp, pulpa dentis*, or the fœtal *tooth-papilla*, which has been reduced in size in the development of the tooth, rises at the bottom of the socket from the alveolar periosteum, penetrates into the fangs, and completely fills the cavity within them and the crown, as a solid but soft, reddish substance, which is rich in vessels and nerves, and everywhere intimately adherent to the inner surface of the dentine. The tissue of the pulp, in so far as it contains vessels, is an indistinctly fibrous connective tissue with very numerous round or elongated nuclei interspersed. On its surface, and seated under a delicate structureless membrane, there is a layer 0·02‴, 0·03‴ to 0·04‴ thick, which consists of several rows of cylindrical or conical nucleated cells, 0·012‴ long, 0·002‴ to 0·003‴ broad, disposed perpendicularly upon the surface of the pulp like a columnar epithelium. Further inwards, these cells are arranged less regularly, and at length pass into the vascular tissue of the pulp without well defined limits by the medium of shorter and more roundish cells. These cells correspond to the formative cells of the dentine, to be afterwards described, and they furnish the materials for the deposition of dentine on the walls of the dental cavity which may occur in the adult. The *vessels* of the pulp are extremely numerous, whence its reddish colour. From three to ten small arteries pass into the pulp of a single tooth, which, at length, produce both in the interior of the pulp and upon the surface of the pulp, a somewhat loose net-work of capillaries 0·004‴ to 0·006‴ wide, from which the veins then arise; at the surface these capillaries here and there present evident loops. The tooth-pulp does not appear to possess any *lymphatics*, but its *nerves* are extremely well developed. Arising from the well-known *nervi dentales*, there passes into each fang a trunk, 0·03‴ to 0·04‴ in size, and, together with it, as many as six or even more fine twigs, 0·01‴ to 0·02‴, which, having nerve-tubes 0·0016‴ to 0·003‴ in diameter, ascend into the cavity without, at first, forming any considerable anastomoses, but giving off separate fibrils, and in the thicker part of the pulp form a richer and richer plexus, with elongated meshes and collections of nerve-tubes, and thus gradually break up into fine primitive fibres, 0·001‴ to 0·0016‴ in diameter. These primitive fibres form very evident loops, but it is uncertain whether these represent the ultimate terminations.

The *gum, gingiva*, is that part of the mucous membrane of the oral cavity, which covers the alveolar borders of the jaws, and embraces the necks of the teeth. It is a light red, vascular tissue, which, owing to the hard subjacent parts, is firm to the feel, although it is in reality soft, and which, where it is applied to the teeth themselves, attains a thickness of ½‴ to 1½‴, bears tolerably large papillæ (0·15‴ to 0·3‴), and possesses a pavement epithelium 0·23‴ to 0·4‴ in thickness between the papillæ. I have not been able to find a trace of *glands* in the gum, and we must be careful not to take for the orifices of glands certain rounded depressions of the epithelium, 0·08‴ to 0·15‴ in diameter, with cornified epithelial cells.

§ 141. *The Development of the Teeth.*—The development of the twenty milk teeth begins in the sixth week of fœtal life, with the formation of a groove upon the upper and lower maxillary border. From the time of formation of these grooves up to the tenth week, *papillæ* gradually arise in them, ten in each jaw, or twenty in all. These *papillæ* or *tooth-germs* are soon separated by transverse partitions, so that each comes to lie in a special cavity. In the fourth month, these cavities become narrower and narrower, the papillæ at the same time assuming the form of the subsequent teeth; and, at length, are perfectly closed, but in such a manner, that over each cavity or tooth-sac, another small recess is formed as *cavity of reserve* for the twenty anterior permanent teeth, of which, even in the fifth month of fœtal life, the tooth-germs are developed. At first, the new cavities lie over the tooth-sacs of the milk-teeth, but they gradually move to the posterior side of them; and, when the bony alveoli of the milk-teeth appear, are received into small dilatations of them, which, in the incisor and canine teeth, become, at last, completely separate from the others, in the two first molars, on the other hand, open at the bottom of the alveoli of the milk-teeth. The tooth-sacs of all these teeth are drawn out at the apex in form of a solid cord, which extends either to the gum or on the two first molars, to the periosteum at the bottom of the two milk-molars, and which has incorrectly been considered as being a conducting band (*gubernaculum*) of the teeth in their eruption.

With respect to the sacs of the three last permanent molars, that of the first arises in the sixteenth or seventeenth week, quite independently, from the posterior extremity of the primitive dental groove, and closes in such a manner, that a *cavity of reserve* remains between it and the mucous membrane (my *Micr. Anat.*, fig. 206). In the seventh or eighth month after birth, the *cavity of reserve* lengthens and extends in an arched form behind the first sac into the alveolar border, produces upon its floor a papilla, upon which it becomes constricted, to form with its lower part the sac of the fourth molar, while the remaining or upper part falls into a line with the other sacs, and is converted into the sac of the wisdom tooth.

The formation of the milk-teeth commences in the fifth month of fœtal life, and in the seventh month they are all in process of ossification. The ossification begins at the apex of the tooth-pulp by the formation of small scales of dentine, which in the molars correspond in number to the prominences of the papilla, or in the crown of the future tooth, but soon coalesce with each other. Immediately after the appearance of a dentinal scale, a thin layer of enamel also arises from the so-called enamel organ at the roof of the tooth-sac (see *infra*), which coalesces with the dentine, and thus forms the first rudiment of the crown. The scale of dentine extends further over the pulp and becomes thicker, so that it is soon seated like a cap upon the pulp, and lastly, embraces it closely and completely like a capsule, whilst the pulp becomes smaller and smaller the more the ossification advances. At the same time, the deposition of enamel follows, and soon proceeds from the entire surface of the enamel-organ, becoming thicker and thicker. Thus, at length, the whole of the enamel is formed around the dentinal rudiment of the crown, whilst the enamel-organ and the tooth-pulp constantly decrease in volume, until the former is reduced to a thin membrane, and the latter approaches the proportions which it exhibits in the fully developed tooth. At this period, there is still no trace of cement or of the fangs; it is not till the crown is tolerably far advanced in development and the tooth is ready for eruption, that they make their appearance. The tooth-germ now grows powerfully in the longitudinal direction, and, the enamel-organ becoming atrophied, only dentine is deposited upon the growing part, viz., the root. The tooth thus forced upwards, begins to be pushed against the upper wall of the tooth-sac and the gums which are firmly united with it, gradually breaks through these parts, which also undergo spontaneous absorption, and, at length, makes its appearance externally. Now the gum contracts around it, whilst the remaining portion of the tooth-sac becomes closely applied to the fangs, and is converted into the periosteum of the alveolus. The milk-tooth is completed, 1, by the growth of the fang in its due length, by which means the crown rises to its normal height; and, 2, by a deposition from the tooth-sacs, which now coalesces with the periosteum of the alveolus; this deposition begins even before the eruption of the tooth, and is converted into the cement, whilst at the same time the tooth becomes still more thickened from within, and the germ correspondingly diminished. In teeth with several fangs, the originally simple germ becomes, during its elongation, divided at its base or adherent part, and a fang is then developed around each division. The eruption of the teeth takes place in the following order; central incisors of the lower jaw from the sixth to the eighth month; central incisors of the upper jaw some weeks later; lateral incisors from the seventh to the ninth month, those of the lower jaw first; anterior molars from the twelfth to the fourteenth month, those of the lower jaw first; canine teeth from the sixteenth to the twentieth month; second molars between the twentieth and the thirtieth month.

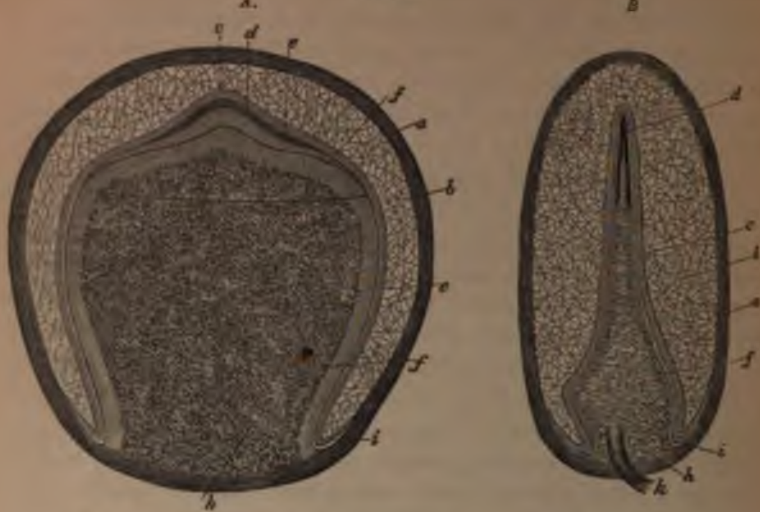
The *permanent teeth* are developed exactly in the same manner as the milk-teeth. Their ossification commences in the first large molars some time before birth, proceeds in the first, second and third year upon the incisors, canines and small molars, and, at length, also involves the second large molars, so that in the sixth or seventh year, forty-eight teeth are contained in the two jaws, viz., twenty milk-teeth and all the permanent, except the wisdom teeth. In the shedding of the teeth, the bony partitions, which separate the alveoli of the permanent from those of the milk-teeth, are absorbed, and at the same time the fangs of the latter disappear from below upwards, in consequence of a process not yet exactly understood. Thus the permanent teeth, whose roots meanwhile elongate, come to lie directly under the loosened crowns of the milk-teeth, which, on the further advancement of their successors, fall out and give place to them. The eruption of the permanent teeth takes place in the following order: first large molar in the seventh year, central incisor in the eighth year, lateral incisor in the ninth year, first bicuspid in the tenth, second bicuspid in the eleventh year, canine tooth in the twelfth year, second large molar in the thirteenth year, third molar or wisdom tooth between the seventeenth and nineteenth years.

The *gum* of the fœtus, and especially of the newly-born infant, is, before the eruption of the milk-teeth, whitish, very firm, and almost of the consistence of cartilage, on which account, perhaps, it has been also called *gum-cartilage*, although, in its structure, it has not the slightest resemblance to cartilage, and consists of the ordinary elements of the mucous membrane, with a considerable intermixture of a more tendinous tissue. The bodies, the size of a millet-seed, described in it by *Serres*, and which are said to be glands which secrete tartar, the so-called *glandulæ tartaricæ*, are collections of epithelium, and probably of a pathological nature (see my *Micr. Anat.* ii. 2, p. 92).

The *tooth-sacs* have an envelope of connective tissue with vessels and nerves, from the floor of which the tooth-germ, *pulpa dentis* arises. This corresponds in form to the future tooth, consisting of an inner part rich in vessels, and subsequently also in nerves, and of an outer non-vascular portion. The latter is bounded by a delicate structureless membrane, the *membrana præformativa* (*Raschkow*), which is of no significance in the formation of the tooth; and *beneath* the membrane are cells 0·016‴ to 0·024‴ long, and 0·002‴ to 0·0045‴ broad, with beautiful vesicular nuclei, and one or more distinct nucleoli, which are placed close to one another, like an epithelium upon the whole surface of the pulp; they are not, however, so sharply limited internally as an epithelium, and there is at least apparently a gradual transition by means of smaller cells between them and the parenchyma of the pulp. Nevertheless in more vascular tooth-pulps, a

Fig. 128.

A. B



A. Tooth-sac of the second incisor of an eight months human fœtus, seen on its broad surface; magnified 7 times. *a.* Tooth-sac; *b.* enamel pulp; *c.* enamel membrane; *d.* enamel; *e.* dentine; *f.* dentinal cells; *g.* boundary of the dentinal scale; *h.* tooth-papilla; *i.* free border of the enamel-organ. *B.* First incisor of the same embryo seen edgeways. Letters as above; *d.* dentinal scale *in toto*; *k.* nerve and vessel of the papilla.

certain limitation arises from this, that the capillary loops of the vessels do not pass in between the cylindrical cells, but terminate close to each other, underneath them, so that the designation of the layer of cells in question as the *dentinal membrane, membrana eboris* appears to be warranted, especially as these cells really yield the dentine.

The *inner parts* of the pulp consist throughout of a more granular or homogeneous, but subsequently more fibrous matrix, with numerous cell-nuclei of a roundish or elongated form, which is to be regarded as a kind of connective tissue. At the period of ossification, vessels are developed in large numbers in the pulp, and the most numerous, perpendicularly deposed loops of capillaries of about 0·006‴ are found principally upon the border of ossification. The nerves accompany the vessels, but are developed subsequently to them. Their number is likewise very considerable, and their distribution in the pulp similar to that in the fully developed teeth.

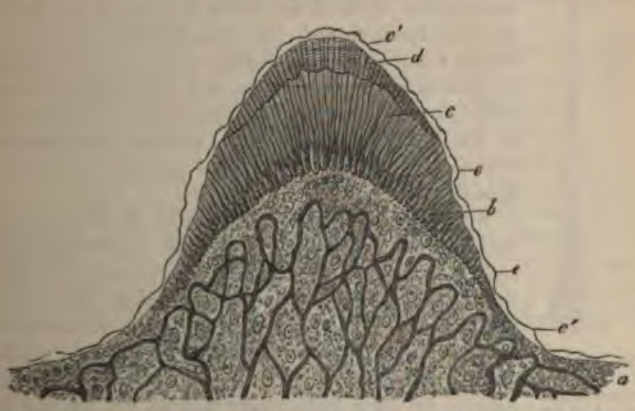
The enamel-organ, *organon adamantinæ*, embraces with its inner concave surface the tooth-pulp in its entire extent, and is connected at its outer side with the tooth-sac, but in such a manner, that it possesses a very small free border at the base of the tooth-germ. Its structure is very peculiar. The principal mass consists of anastomosing stellate cells (fig. 128 *b.*), or reticulated connective tissue, which contains in its interspaces a large quantity of fluid, rich in albumen and mucus. This gelatinous areolar tissue is thickest immediately before the commencement, and in the first stages, of ossification. Thus in the fifth and sixth months, it is $\frac{1}{10}$ to $\frac{1}{3}$ of a Vienna line, in the newly-born infant, or, on the other hand, only 0·16‴ to 0·2‴. At this period, it also possesses vessels in its outer third; and its mesh-work has become metamorphosed into true connective tissue (fig. 129). Upon the inner side of the spongy tissue of the enamel-organ, there is situated the so-called *enamel-membrane, membrana adamantinæ* (*Raschkow*), a genuine cylinder-epithelium, with cells which measure 0·012‴ in length, 0·002‴ in breadth, are finely granular and delicate, and contain elongated, round nuclei, often situated at the apices of the cells.

Fig. 129.

Section of the enamel-organ from the sac of a molar tooth of a newly-born infant; magnified 250 times, *a*. Dental sac; *b*. vascular part of the enamel-organ with a somewhat denser tissue towards the non-vascular part or the spongy tissue *corpus spongiosum*; c. *d*. enamel membrane.

The *development of the tissues of the tooth* has always been regarded as a very difficult subject of inquiry. The phenomena appear most simple in the *enamel*, and all authors have, hitherto, assumed with *Schwann*, that the enamel-fibres are nothing else than the ossified cells of the enamel membrane. *Huxley*, however, has recently asserted (l. c.) that this cannot be the case, *seeing that the enamel, in all stages of its development, is covered by the membrana præformativa of the dental pulp, and separated by it from the enamel-membrane.* According to *Huxley*, the enamel is formed *independently of the enamel-membrane, and beneath the membrana præformativa,*

Fig. 130.



Section of the crown of a human fœtal molar tooth, in which the formation of the dentine and of the enamel has commenced a short time since, *a*. Tooth-pulp, or tooth-germ, with the vessels; *b*. so-called dentinal membrane, consisting of dentinal cells; *c*. fully formed dentine; *d*. fully formed enamel; *e*. *membrana præformativa*; *e*. *membrana præformativa* (*enamel-epidermis*) after treatment with acetic acid. After *Lent*.

which is finally converted into the dental cuticle of the fully-developed tooth, discovered by *Nasmyth*; still he confesses, that he is unable to give any further explanation of the process. *Huxley's* observations have been repeated by one of my most able pupils, *E. Lent*, and in so far verified, that undoubtedly a delicate structureless membrane may, at all times, be separated from the surface of the developing enamel when treated with diluted acids.

which membrane, so long as the dentine is not fully formed, is continued into the membrana præformativa of the tooth-pulp, and thus gives rise to the appearance as if the enamel were developed beneath the *membrana præformativa*. If we assume, for the moment, that this is correct, the following seem to be the only admissible explanations of the formation of the enamel:

1. The enamel-fibres are produced by a secretion of the cells of the enamel-membrane, which penetrates the *membrana præformativa* in a fluid condition, but hardens and ossifies beneath it.

2. The enamel-fibres are formed by the dentine from an exsudation furnished by the dentinal canals. Of these two possibilities, the second is of such a nature, that I at least will not venture to enter further upon it, seeing that according to this view, the formation of regular fibres in the enamel, its growth in thickness by means of the apposition of new layers upon its outer surface, are facts wholly unexplained; at the same time the former assumption, although the more probable, is not without many difficulties (see my *Handbook*, second German Edition).

Fig. [illegible]

Isolated dentinal cells with processes, i.e., dentinal tubes. a, of man; b, of the horse. After *Lent*.

As in the formation of the enamel, so in that of the dentine, the whole of the pulp is not concerned, but only the outermost epithelial-like cell-layer of it, and I deny that the whole of the pulp is simply converted from without inwards into dentinal cells and ossified, but think it far more probable, that, like the spongy body of the enamel-organ, it serves for the formation of the dentine, only by supporting the vessels, which are necessary for the growth of the dentinal cells. Its decrease is also very readily conceivable without assuming an ossification of it from without inwards, and, like the decrease of the contents of the wide Haversian canals of fœtal bones during the formation of lamellæ upon the walls of the canals, is simply owing to a gradual absorption of its soft tissue; in which explanation there is no need to assume that its vessels undergo a retrogressive process, in any considerable degree.

With regard to the *formation of the dentine* from the dentinal cells, it is certain, that no other tissue than the cells contributes anything to the result, and *Huxley* is decidedly wrong in maintaining that no histological element of the pulp is concerned in the formation of the tooth. The manner in which the cells in question are transformed, after remaining so long in doubt, appears, at length, to have been really cleared up by the investigations of *Lent*. Some years ago, I discovered upon the human dentinal cells filamentous processes extending into the young dentine, which I supposed to be dentinal canals; still I was not at that time able to raise this supposition to a certainty. This has been done by *Lent*, who has succeeded in isolating the cells in question with complete dentinal canals prolonged from them, in growing teeth which were macerated to disintegration in hydrochloric acid. This once established, the formation of dentine must, as *Lent* concludes, be conceived to take place in the following manner:—

1. *The dentinal canals are direct processes of the whole dentinal cells*, which processes may send out subordinate branches, and anastomose by means of them. To all appearance, a single cell seems, in many cases, to be sufficient to form an entire dentinal canal, or at least a very large part of one.

2. *The matrix of the dentine is not formed of the dentine-cells, but is a secretion of these cells and of the tooth-pulp: in other words, an intercellular substance.*

Taking all these facts together, it results, that the canals of the dentine arise by the direct metamorphosis of a histological element of the pulp, viz., the dentinal cells, whilst the matrix of the dentine is to be regarded as a secretion from these cells and the vessels of the pulp. My opinion thus holds a middle place between the old excretion-theory, according to which the whole dentine is an excretion of the pulp, and the theory of metamorphosis, according to which it is constructed, entirely and alone, out of certain histological elements of the pulp. On the other hand, I cannot accede to the deposition-theory of *Huxley*, according to which the dentine is deposited in the pulp without any of the histological elements taking part in its formation; but I agree with him in this, that the formation of *dentine* takes place beneath the *membrana præformativa*. Moreover, I may further observe that in animals, and perhaps in man, an ossification of the inner part of the pulp appears to occur as a pathological condition; for we meet with dentine containing vessels (vaso-dentine, *Owen*), according to *Tomes*, even in man; and in the teeth of certain animals, the pulp is entirely absent. In such cases, the pulp simply ossifies, probably like connective tissue, which also agrees very well with the fact, that the vaso-dentine much more resembles ordinary bone than dentine.

During the ossification of the dentine a deposition of calcareous salts takes place, at least in man, in the newly-arisen, morphologically characterised, but still little hardened dentine, frequently in such a manner that the *whole* appears to consist of *isolated globules*. These globules, which are seen both in the primitive scales of dentine and in later stages,—especially at the border of a fang of a larger tooth, when viewed from the outer side,—subsequently disappear when the formation of dentine goes on normally, calcareous earth being deposited between them, so that the dentine becomes quite homogeneous and more translucent; in the opposite case, they remain persistent in larger or smaller numbers, and the spaces between them, which are merely the above-mentioned interglobular spaces, contain incompletely ossified dentine.

The *formation of the cement* proceeds, according to my observations, from that part of the tooth-sac which is situated between the pulp and the enamel-organ, and commences even before the eruption of the tooth, as soon, indeed, as the fang begins to be formed. At this period, the tooth-sac becomes elongated at its lower part, is closely applied to the developing fang, and, from its rich network of vessels, furnishes—as the periosteum does during the growth in thickness of the bones—a soft blastema, in which nucleated cells become developed, and which then immediately ossifies. Accordingly, the cement is not formed by the ossification of the tooth-sac itself. I observed the first traces of it in newly-born infants, in the form of isolated scales of an elongated or roundish shape, which firmly adhered to the dentine of the still very short fangs, and looked exactly like the developing osseous substance in the cranial bones. The smallest of these scales presented distinct lacunæ, and had a slightly yellow colour, but were still quite soft and transparent, and passed, at the borders, imperceptibly into a very clear blastema, containing cells. In larger ones the borders were similar, but the middle was darker and firmer; and, in like manner, every intermediate condition was observed up to that of true bone, without any deposition of calcareous granules. As the fang lengthens, new bony scales like the above make their appearance, and gradually coalesce from above downwards into a simple layer, upon which, then, new bone is deposited, in the same manner, from without, to such amount as is necessary to form the entire thickness of the cement.

The *enamel-cuticle* must, as we have already seen, be regarded as the original *membrana præformativa*, which remains during the formation of the tooth, and becomes somewhat thickened. Upon the dentine, the *membrana præformativa* is covered by the deposition of the cement, and is afterwards no longer demonstrable as a special layer.

If, finally, we cast a glance at the different substances of the tooth, and their position relatively to each other, it is seen that, although agreeing in certain respects, they cannot be brought under one category. Dentine and cement are much more closely related to each other than to enamel; and the dentine is simply osseous tissue, whose matrix is pure intercellular substance, and whose cells have become transformed into long anastomosing canals. In many cases, also, the cement, or bone, and dentine are very nearly related. This is especially the case when, on the one hand, the dentine is traversed by numerous Haversian canals, and, on the other, when the cement possesses greatly elongated cells with numerous processes, and also vascular canals, or contains, along with but few lacunæ, numerous parallel canals like dentinal tubes; and it is readily conceivable that the dentinal canals frequently anastomose with the bone-cells of the cement. The dentine also agrees very much with the cement, and the bones in general, in its manner of growth; and the pulp may be compared to the periosteum, and the dentine-cells to the cell-layer furnished by that membrane. The enamel may be most fitly compared with dentine which contains no tubes, such as that which is met with in the outermost layers of the teeth of fishes, and it agrees with the matrix of the dentine, at least in this respect, that it is formed by an excretion from cells. When canals occur in the enamel, it has a considerable resemblance to dentine; but these canals probably have quite a different signification from those in the dentine, namely, that of cavities produced by absorption. The enamel has, for the most part, no analogy with the cement; still there occurs a homogeneous cement with an indistinct transverse striation, which, at least in outward appearance, bears some resemblance to enamel, and is, perhaps, also nearly related to the latter in its development. On considering the signification of the parts from which the different substances are formed, it may be inferred, that the dentine, inasmuch as it is formed in the vascular parts of the oral mucous membrane, is *a true production of the mucous membrane*, that the enamel is an epithelial structure, and that the cement is a superadded substance furnished by the mucous membrane.

§ 142. The fully-developed tooth, although a hard structure, is not entirely devoid of active vitality, as is best shown by the different diseases to which it is subject. The functions of the lacunæ of the bones and their canaliculi, are performed here by the dentinal canals and their ramifications, the lacunæ and canaliculi in the cement, and the spaces between the prisms of the enamel. All these spaces, during life, contain a fluid which, on the one hand, comes from the vessels of the pulp, and, on the other, from those of the alveolar periosteum, and furnishes the conditions necessary for a change of material, slow though it be. It is, for the present, impossible to state exactly how the change of substance is effected; still, from the circumstance that the fully-developed dentine is not coloured by madder (*Hunter*, *Flourens*, and others; also *Henle*, p. 878), we may conclude, at least, that the change is much less energetic than in bones, and, perhaps, takes place in such a manner that the calcareous earths are not at all, or only very slowly, renewed. The dentine is, doubtless, best provided with a supply of juices, since it is traversed by very numerous, anastomosing canals; still a regular circulation of these fluids is no more admissible in dentine than in bone; we must rather assume that the movement of fluid takes place sometimes in one direction, and sometimes in another, according to the degree of exsudation and absorption by the pulp, and of the waste of material in the tooth itself; according also to the amount of nutritive matter bestowed on the enamel and cement, and perhaps, too, of that which is given off by these tissues outwardly. The enamel is, indeed, not impermeable; but it allows fluid to pass through it with difficulty, which may be best understood from the fact, that the nerves of the pulp are not affected by acids so long as the enamel-covering is complete, but readily so, when, as upon the incisors, the dentine is exposed. The enamel is undoubtedly the hardest of the dental substances, almost destitute of an organic basis, and without a constant system of canals. Still more impenetrable than the enamel, is, perhaps, the enamel-cuticle, which, also, is with great difficulty attacked by chemical agents; and these two substances are, accordingly, excellently adapted as protecting coverings for the teeth. The teeth acquire sensibility through the nerves of their pulp, and they are sensible both to simple contact, and to heat and cold, as well as to chemical influences. Mechanical impressions of low intensity can operate only when propagated to the pulp by vibrations of the dental substance; and it is, therefore, the more surprising, that the teeth have a certain sensibility for locality, so that we can distinguish whether they are touched on the outside or inside, above or below, on the right or the left. The tactile sensibility of the teeth is also tolerably fine, especially upon the masticating surface, where minute foreign bodies, as hairs or grains of sand, are distinguishable when the masticating surfaces are rubbed upon one another; and its intensity is, at any rate, exceedingly great in disease, which is sufficiently explained by the large supply of nerves in the pulp, and the facility with which they may be compressed within their hard enclosure.

In old age, the teeth become denser, the cavity of the pulp gets filled with a kind of irregular dentine, and even completely obliterated, which, perhaps, is the cause of the natural falling out of the teeth. In certain cases, according to *Tomes*, the fangs are found, in old age, transparent, like horn.

Respecting the pathological conditions of the teeth, the following facts may be noticed. In exceptional cases, after the falling out of the permanent teeth, their place may be supplied by a third dentition; but milk-teeth not unfrequently remain persistent beyond the usual period, and we must be on our guard against taking a retarded second tooth for one of a third set. Extracted teeth can sometimes be re-implanted with success (in fifteen months, an extracted canine tooth of the upper jaw was again completely fastened). Teeth occur as an abnormal formation, especially in the ovaries, but also in other parts. Fractures of the teeth, if they take place within the alveoli, may heal by means of imperfect dentine or cement; but a regeneration of worn-off parts is met with only in animals (rodentia, *e.g.*), in which the teeth grow continually. *Hypertrophy* of the cement, so-called *exostosis*, also dental formations upon the walls of the pulp-cavity and ossification of the pulp itself, are extremely frequent, and are the consequences of chronic inflammations of the periosteum of the pulp. A partial disappearance of the root is likewise not unfrequent. *Necrosis* of the teeth takes place when the periosteum is detached from the tooth, or when the pulp itself has perished; and in this condition the teeth become rough and dark, or black, and fall out. The true nature, as well as the cause of caries of the teeth, is doubtful. It attacks false as well as living teeth (*Tomes*), and always commences externally and from the enamel-membrane (*Ficinus*); whence a very essential share in its production has been ascribed to the fluids of the mouth. By this, however, it is not meant to assert, that in living teeth there may not be a greater predisposition to caries in some than in others, possibly because some peculiarity in their chemical composition or mode of nutrition renders them less capable of resistance. At any rate, caries is not merely a solution of the teeth by the fluids of the mouth, for a putrefactive decomposition of the organic parts of the tooth, which is accompanied by the development of infusoria and fungi, goes on at the same time; nay, the latter, according to the statements of *Ficinus*, appear to play the chief part in this process, inasmuch as caries proceeds principally from those parts of the tooth where the organisms in question may grow undisturbed, as the fissures and small pits in the enamel, the depressions on the crowns of the molars, and the crevices between the teeth; but not in other places where the dentine may have been exposed, as upon the masticating surface, on filed parts, etc. In *caries*, the discoloured enamel-cuticle, which is beset with the growing organisms (an *infusorium*, similar to *vibrio*, which *Ficinus* calls *denticola*, also *fungi*, *leptothrix buccalis* [*Erdl*, *Klenke*, *Tomes*, *Kölliker*]), first loses its calcareous salts, and then breaks up into angular, cell-like particles, as if it had been treated with hydrochloric acid. The same process then advances through the enamel to the dentine, always softening it first, so that it contains only ten per cent. of ashes (*Ficinus*), and then disintegrating it. The dentine suffers more than the enamel; and its tubes first become filled with the fluid arising from the decomposition, which may be conducted to the pulp and cause pain, unless, as *Tomes* found, the dentinal tubes in the adjoining healthy portions are obliterated by deposit, or the pulp is protected by a new formation of dentine in the cavity (*Ficinus*, *Tomes*). Subsequently, a brownish matter is deposited in the tubes, and then the intermediate substance breaks down completely. In this manner, the process of destruction advances further and further, until, at length, the crown breaks down, and the fang also loosens and falls out. In jaundice, the teeth not unfrequently assume a slightly yellow colour, which is occasionally almost as deep as that of the skin, and they are said to be often red in suffocated persons, both of which phenomena can only be explained by the passing of the colouring matter of the bile and blood into the dentinal tubes. In rickets, the teeth remain unaffected. In the mucus upon the teeth, the *leptothrix buccalis* is always to be found growing abundantly in a finely granular matrix, which surrounds mucous corpuscles or epithelial plates; in it we also meet with the *infusoria* of the carious teeth, and earthy deposits from the fluids of the mouth. When this mucus collects in larger quantities, it hardens and forms the *tartar of the teeth*, which, according to *Berzelius*, consists of: earthy phosphates, 79·0; mucus, 12·5; ptyalin, 1·0; organic matter, soluble in hydrochloric acid, 7·5.

For the investigation of the teeth, fine polished sections and preparations softened in hydrochloric acid are of service. Since fine sections may be readily obtained in England by purchase, we shall not enter further here into the method of preparing them. If it be desired to obtain an entire tooth so soft that the tubes may be isolated, it must be allowed to lie for about eight days in concentrated hydrochloric acid; thin sections of the tooth-cartilage are then to be treated, from twelve to fourteen hours, with sulphuric and hydrochloric acids, and some hours with diluted caustic soda and potass. It is also very instructive, to macerate thin sections in acids, and to examine them from time to time upon a plate of glass, till they are completely disintegrated. Prisms of enamel may be easily isolated in growing enamel; the transverse lines are best seen by touching with hydrochloric acid, and the transverse sections of the prisms may be tolerably well seen upon longitudinal sections of certain layers. The commencement of the teeth-rudiments is to be studied in embryos of two, three, and four months, with a simple lens, on cross sections of the parts hardened in spirit. The structure of the tooth-sac and the formation of the teeth, in fœtuses of four, five, and six months, and in newly-born infants, in fresh subjects, and, for the relations of the enamel-organ, also in alcohol preparations, in which, also, its structure is well preserved. The pulp of the fully-developed teeth is obtained by breaking them in a vice, and their nerves are best seen on the addition of diluted caustic soda.

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III.—OF THE ORGANS OF DEGLUTITION.

1. PHARYNX.

§ 143. With the *pharynx*, the digestive tract begins to become more independent, and to assume a special layer of transversely striped muscles, the *constrictores* and *levatores*, which, however, do not encircle it completely, and arise, for the most part, from bones. The thickness of the walls of the pharynx, which is on an average 2‴, depends chiefly upon this muscular layer, which is enveloped externally by a tense fibrous coat of connective tissue and elastic fibres, and separated internally from the *mucous membrane* by a layer of submucous tissue. The mucous membrane is paler than that of the oral cavity, and differs somewhat in structure in the upper and lower half of the pharynx, In the latter place, *i. e.*, below the palato-pharyngeal arches, or in the part through which the food passes, it possesses a pavement epithelium, of the same structure and thickness as that in the walls of the oral cavity. Above these arches, on the other hand, —consequently upon the posterior surface of the soft palate, the superior surface of the uvula, around the posterior openings of the nares, and the orifices of the Eustachian tubes, and upon the vault of the throat,—the epithelium of the pharynx is ciliated, and is similar in nature to that in the nose and larynx, of which a description will be found in the account given of their organs. In this upper or *respiratory* section of the pharynx the mucous membrane is also redder, thicker, and richer in glands, but otherwise of much the same structure as below, except that here no papillæ are met with, which, however, even in some parts of the lower section, are but little developed and sparingly present, or even wanting altogether. Compared with that of the oral cavity, the pharyngeal mucous membrane has, as I find, both more abundant and stronger elastic tissue, which, in the deeper layers, forms very dense and continuous elastic coats.

The pharynx contains two kinds of *glands*: ordinary racemose *mucous glands* (see above, § 133), and *follicular glands*. The former, $\frac{1}{3}'''$ to $1'''$ in size, and with conspicuous openings, are met with especially in the upper part of the pharynx, where upon the posterior wall, in the neighbourhood of the pharyngeal orifices of the Eustachian tubes, and upon the posterior surface of the *velum*, they form a continuous layer; further downwards, they decrease in numbers towards the œsophagus. The upper vaulted part of the pharynx presents both simple and compound *follicular glands* analogous to the tonsils. I find *constantly* at the part where the mucous membrane is firmly attached to the base of the cranium, a collection of glands, $1'''$ to $4'''$ thick, and extending from the one Eustachian tube to the other, which, except that they are smaller, agree in all essential points of structure with the tonsils (see § 134). Besides this mass of glands, the largest of which are found in the middle of the roof of the pharynx, and in the recess behind the opening of the Eustachian tubes, — and which, in old people, frequently present widened cavities filled with purulent matter, whilst in children and new-born infants they are mostly hyperaemic like the tonsils, — there occur around and upon the openings of the Eustachian tubes, also towards the posterior openings of the nares, upon the posterior surface of the velum, and the lateral walls of the pharynx, as far as the level of the epiglottis, smaller and larger follicles in greater or less number, whose size is too great to be openings of mucous glands, and which, probably, have the same structure as the simple follicles of the root of the tongue, and receive the excretory ducts of the mucous glands.

The mucous membrane of the pharynx is rich in *blood-vessels and lymphatics*. The former form, superficially, a rather elongated mesh-work, but also ascend into the rudimentary papillæ in short loops. The *nerves* are very numerous, and form superficial and deeper plexuses; the former with fine fibres, 0·001‴ to 0·0015‴ in diameter, which here and there divide, but whose ultimate termination is lost to view.

2.—ŒSOPHAGUS.

§ 144. The walls of the œsophagus, $1\frac{1}{3}$‴ to $1\frac{3}{4}$‴ thick, consist externally of a fibrous coat of connective tissue, with well-marked elastic fibres. Then follows a *muscular coat*, $\frac{3}{4}$‴ to 1‴ thick, with an outer longitudinal layer of fibres, 0·5‴ thick, and an inner circular one, 0·24‴ to 0·3‴, which lie close to each other. The longitudinal fibres arise by two bundles from the *constrictor infimus*, and by a third from the cricoid cartilage; and from this point, both layers extend as far as the stomach, into the muscular coat of which they are in part continued. In the upper third of the œsophagus, as far as its entrance into the thorax, these muscles are *transversely striped*, and occasionally form distinct anastomosing bundles, 0·04‴ to 0·24‴ in diameter. Further downwards, *smooth* muscular fibres of the same structure as in the intestine make their appearance, first in the circular and then in the longitudinal layer, and increase more and more in number, till at last, in the lower fourth, the smooth fibres form by far the majority. According to *Ficinus*, however, single transversely striped fibres are met with as far as the cardia. *Treitz* describes the longitudinal fibres as commencing by elastic fibres, which are interposed between the transversely striped bundles. Numerous longitudinal bundles also branch off from the outer surface of the œsophagus, and are lost, partly among the elastic fibres of the outer coat, partly on the neighbouring organs, especially on the posterior wall of the trachea, on the left *mediastinum* (*musculus pleuro-œsophageus, Hyrtl.*), or the *aorta* and left *bronchus* (*musculus broncho-œsophageus, Hyrtl.*). Most internally follows the pale-reddish, inferiorly whitish mucous membrane, which is separated from the

Fig. [illegible].

Muscular fibre-cells from the œsophageal mucous membrane of the pig, after treatment with nitric acid of 20 per cent. Magnified 100 times.

muscular coat by a white yielding layer of submucous connective tissue (*Tunica nervea* of older writers). Of its entire thickness,—which amounts to 0·36‴ to 0·45‴,—0·1‴ to 0·12‴ belongs to its *pavement-epithelium*, which presents the same structure as in the oral cavity, with this exception, that the true epithelial plates, perhaps, constitute the half of the whole, and may be stripped off, after short maceration in the dead body, frequently without further preparation, and partly along with the deeper layers, in the form of large white shreds. The proper mucous membrane, on an average 0·3‴ in thickness, possesses numerous conical papillæ, 0·04‴ to 0·05‴ in length, and consists of ordinary connective tissue, with fine elastic fibres, in which, however, as *Brücke* and I have found, a large number of *smooth muscular fasciculi* exist, also more isolated groups of ordinary fat-cells and *small racemose mucous glands*.

The œsophagus is moderately well supplied with *blood-vessels* and *lymphatics*; the former form simple loops in the papillæ, and a moderately wide capillary network at the base, as on the pharynx. Nerves are also observed in considerable numbers in the mucous membrane, with fine fibres 0·0012‴ to 0·0015‴ in diameter; still I have not, hitherto, succeeded in following them into the papillæ, or recognising divisions or other terminations of them.

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IV.—OF THE STOMACH AND INTESTINES.

§ 145. This portion of the alimentary tract is the most free in its position, and, throughout nearly its whole extent, is supported in the great cavity of the abdomen by special ligaments, named *mesenteries*. The walls of its several divisions, excepting a small portion of the *rectum*, are everywhere formed of three coats—namely, a *serous*, furnished by the peritoneum, a *muscular* of two or even three layers, and a *mucous*—and contain in the latter very numerous glandular structures, which are divisible into three groups, *racemose mucous glands*, *tubular glands*, and *closed follicles*.

§ 146. The *peritoneum* is considerably thicker and firmer in its outer or parietal layer than in the inner or visceral (in the latter, 0·02‴ to 0·03‴; in the former, 0·04‴ to 0·06‴); it presents, however, in both parts essentially the same structure, and consists principally of connective tissue, in distinct, variously decussating bundles, and numerous networks of elastic fibres, which are thicker in the parietal portion. A *loose subserous* connective tissue, with more or less fat, connects the peritoneum with subjacent parts, or holds its layers together where the membrane forms folds, as in the mesentery. Under the visceral layer, however, the subserous connective tissue is, except in certain places (*colon, appendices epiploicæ*), but little developed, or even not at all demonstrable, as in certain peritoneal ligaments. The free surface of both peritoneal lamellæ is covered by a simple pavement-epithelium, whose slightly flattened, polygonal, nucleated cells amount on an average to 0·01''' in diameter, and are so firmly united together, that the free surface of the serous membrane appears perfectly smooth, and, from its being always moistened, also shining.

The blood-vessels of the peritoneum are, in general, few. They are most numerous in the omenta and in the visceral layer, also in the subserous tissue, in which latter alone, lymphatic vessels have, hitherto, been demonstrated. The *nerves* also are not very numerous; they may be shown especially in the omentum, the mesentery, on the diaphragm, and the spleen, and in the hepatic ligaments, to which they may be traced from the phrenic, in company with the arteries.

§ 147. *Muscular Coat.*—All parts of the alimentary tract, from the stomach to the rectum, possess a special muscular coat, which, however, does not everywhere present the same conditions.

In the stomach, the muscular coat is not everywhere equally thick; at the fundus it is very thin ($\frac{1}{4}'''$ to $\frac{1}{3}'''$), in the middle, about $\frac{1}{2}'''$, in the pyloric region, $\frac{3}{4}'''$ or even $1'''$ thick. It consists of three incomplete layers, viz., 1st, most externally, *longitudinal fibres:* these consist of fibres radiating from the longitudinal fibres of the œsophagus (those on the small curvature extending to the pylorus, whilst the others run out free upon the anterior and posterior wall of the stomach and upon the upper side of the fundus), and of independent fibres upon the right half of the stomach, from which part, tensely stretched, they pass upon the duodenum: 2nd, *circular fibres,* which pass from the right side of the cardia onwards as far as the pylorus, where they are thickest, and form the *sphincter pylori,* as it is termed: 3rd, *oblique fibres,* most internally, which, being connected with certain circular bundles at the *fundus,* embrace that part in form of loops, and run obliquely upon the anterior and posterior wall of the stomach towards the larger curvature, where they are partly attached by elastic tendons (*Treitz*) to the outer surface of the mucous membrane, and partly connected with each other (see the excellent figures in *Beau* and *Bonamy*, iii., Pl. 14).

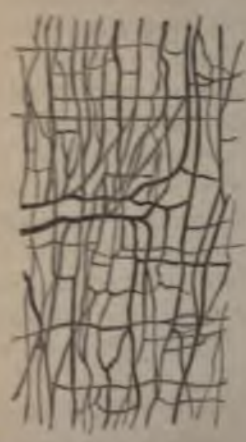
In the *small intestines*, the muscular coat is somewhat thicker upon the duodenum and the upper parts than on the lower, generally $\frac{1}{4}'''$ to $\frac{1}{6}'''$, and is composed only of longitudinal and transverse fibres. The former are always thinner, and do not form a complete layer, since they are very scanty, or even entirely absent on the mesenteric border. They are usually most distinct on the free border; still, even here, they are liable to be easily stripped off with the peritoneum, so that the circular layer is exposed. The latter is complete, enters into the folds of the ileocolic valve (*valvula Bauhini*) but not into the folds of *Kerkring (valvulæ conniventes)*, and consists of circular fasciculi, which not unfrequently join together at acute angles. The *musculus suspensorius duodeni (Treitz)* is a smooth muscle $1\frac{1}{2}$ inch long, about 1 inch broad, and $1'''$ thick, which arises from the upper border of the duodenum at the lower end of the latter, and passes, by means of elastic tendons, into the dense connective tissue surrounding the cœliac artery, and is also connected with slips coming from the inner pillars of the diaphragm (l. c. tab. ii).

Upon the large intestine, the longitudinal fibres are reduced to the three *ligamenta coli*. These are muscular bands, $4'''$ to $6'''$ or even $8'''$ broad, and $\frac{1}{3}'''$ to $\frac{1}{2}'''$ thick, which commence upon the *cæcum* and coalesce upon the sigmoid flexure into two bundles situated on the right and left, which, in conjunction with special independent fibres, form the longitudinal muscular layer of the rectum. Beneath these ligaments, there is situated a continuous circular layer of fibres, which is thinner than upon the small intestine, and particularly developed in the duplicatures, well known under the name of *plicæ sigmoideæ*.

The rectum has a muscular layer upwards of $1'''$ in thickness, in which the longitudinal and at the same time thicker fibres are situated externally, and the circular fibres internally. The lower, somewhat thicker, termination of the circular muscular coat forms the *sphincter ani internus*, with which the transversely striped *sphincter externus* and *levator ani* are connected. The longitudinal fibres terminate, according to *Treitz*, with elastic tendons which are partly inserted into the pelvic fascia, partly penetrate the *sphincter ani externus*, and are lost in the subcutaneous tissue of the region of the anus. Nevertheless, the longitudinal muscular layer beneath the pelvic fascia is thicker, which, according to *Treitz*, is owing to the additional fibres coming from the fascia, the levator and the coccyx (*musculus recto-coccygeus*, *Treitz*), some of which also become intermingled with the circular muscular fibres.

All the muscles of the proper intestine belong to the smooth or unstriped (vegetative, organic) muscles, as they are termed (see § 29). Their elements, or the fibre-cells, are fusiform, 0·002‴ to 0·003‴, broad in the middle and flattened, 0·06‴ to 0·1‴ long, pale and homogeneous, with a nucleus 0·006‴ to 0·012‴ long, 0·001‴ to 0·0028‴ broad, which, according to *Lehmann*, is invisible in muscles which have been macerated in water, and, according to *Henle*, completely disappears on commencing putrefaction; which phenomenon I am disposed to ascribe to the escape of the nuclei from the fibre-cells, which happens with extreme facility. Many of the fibres are marked with nodular swellings, frequently, also, by zig-zag curvatures, which are especially frequent in alcohol-preparations, and occasion the *transversely banded* appearance of the entire fasciculi of such muscles. The fibre-cells of the different muscular strata are ranged alongside each other, and cohere longitudinally and transversely, so as to form slender muscular bands, which then, being severally enveloped in some connective tissue, and frequently united into thicker bundles, form the thicker or thinner muscular coats of the different regions, which coats are themselves likewise invested by considerable layers of connective tissue, and separated from the neighbouring parts.

Fig. 133.



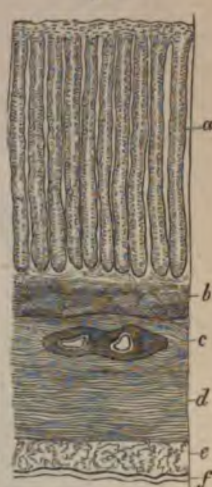
Blood-vessels of the smooth muscular fibres of the intestine, from an injection by Gerlach. Magnified 45 times.

The blood-vessels of the smooth muscles are very numerous, and their capillaries, 0·003‴ to 0·004‴ broad, form a well-characterised network with rectangular meshes. Nothing is known about the lymphatics of the muscles themselves; and the condition of the nerves is likewise unascertained, except that *Ecker* observed divisions of fine nerve-fibres in the muscular coat of the stomach of the frog and rabbit.

MUCOUS MEMBRANE OF THE STOMACH.

§ 148. In the stomach, the mucous membrane is soft and lax, and, during digestion, bright greyish-red in colour, passing into rose-red, excepting a small grey zone, $\frac{3}{4}$ of an inch broad, at the pylorus, with sometimes a corresponding one upon the cardia; at other times, it is greyish. In the empty stomach, the inner surface presents folds, mostly longitudinal, which, however, become effaced when the organ is filled. Besides these larger plicae, there are, especially in the pyloric part, around the openings of the tubular or gastric glands, small reticulated folds, or even isolated villi (*plicæ villosæ*, *Krause*), 0·024''' to 0·048''', or even 0·1''' in height ($\frac{1}{30}$''' to $\frac{1}{20}$''', *Krause*). Moreover, the mucous membrane, especially in the right part of the stomach, is not unfrequently divided by shallow depressions into slightly raised polygonal spaces, $\frac{1}{2}$''', $1\frac{1}{2}$''', to 2''' in diameter; which, so called '*Etat mamelonné*' of pathological anatomists, may be found in perfectly healthy stomachs. The mucous membrane is thinnest ($\frac{1}{6}$''' to $\frac{1}{4}$''') at the cardia, becomes thickened in the middle up to $\frac{1}{2}$''', and in the pyloric part reaches $\frac{3}{4}$''' and 1'''—a difference which is entirely to be ascribed to its layers of glands, inasmuch as its epithelium and muscular layer have everywhere nearly the same thickness. The submucous tissue is abundant, and contains, as throughout in the intestine, separate fat-cells.

Fig. 134.



Perpendicular section through the coats of the stomach of the pig, from the pylorus; magnified 30 times. *a.* Glands. *b.* Muscular layer of the mucous membrane. *c.* Submucous tissue (*tunica nervea*), with cut vessels. *d.* Transverse muscular layer. *e.* Longitudinal muscular laminæ. *f.* Serous membrane.

§ 149. *Glands of the Stomach.*—The glands of the stomach are divisible into *mucous* and *peptic glands*. The latter, the most important parts of the mucous membrane, appear in two forms, which, however, are not to be regarded as sharply distinguished. The one set, or the *simple tubular*, lie in the large middle zone of the stomach, which is bright red during digestion, and, lying close to each other and preserving a tolerably straight direction, extend through the entire thickness of the mucous membrane as far as its muscular coat. They are, consequently, according to the region of the stomach,

$\frac{1}{5}'''$ to $\frac{3}{4}'''$, or even $1'''$; on an average, $\frac{1}{2}'''$ long. They always begin in groups of several together at the bottom of very shallow depressions of the surface of the stomach, which scarcely deserve to be ranked among the glands, as cylindrical tubes, $0{\cdot}03'''$ to $0{\cdot}04'''$ in breadth, which, in their passage downwards, often become narrowed to $0{\cdot}014'''$ to $0{\cdot}02'''$, and terminate with a flask or club-shaped enlargement, $0{\cdot}02'''$ to $0{\cdot}026'''$ or $0{\cdot}036'''$ in diameter. The lower third of the glands, especially in the neighbourhood of the pylorus, is mostly of serpentine form, frequently even spirally twisted; and it is frequently divided into two short branches; upon the lower two-thirds of the glands, also, one or more short blind appendages are not unfrequently met with. Nevertheless, apart from the simple slight dilatations, which, undoubtedly, are very common, but which must be distinguished from true blind appendages, a decided majority of the glands of this region are simple; and glands which might be correctly called racemose, do not occur in it. Each gastric gland is surrounded by a delicate *membrana propria*, and is filled with the so-called *peptic cells*—finely granular, polygonal, nucleated cells, $0{\cdot}006'''$ to $0{\cdot}01'''$ in size—which, sometimes in form of a simple epithelium, surround a narrow cavity, sometimes completely fill the tubes of the *membrana propria*, and at the bottom of them invariably have less distinct cell-walls than in the upper parts.

Fig. 135.

Compound peptic gland from the human stomach, magnified 100 times. 1. Common excretory cavity (stomach-cell, *Todd* and *Bowman*); 2. the tubes with peptic cells.

A narrow zone upon the cardia contains compound tubular gastric glands (fig. 135). They begin with a duct, $0{\cdot}04'''$ to $0{\cdot}08'''$ long, $0{\cdot}03'''$ to $0{\cdot}04'''$ broad (stomach-cell, *Todd* and *Bowman*), which is lined by epithelium-cylinders, and then, almost as from a point, divides first into two or three, and then into from four to seven nearly equally long, cylindrical tubes, beset or filled with peptic cells; these tubes then run parallel to each other into the deeper portion of the mucous membrane. Moreover, the glands in question are especially characterised by the extremely numerous and very considerable simple dilatations of their terminal tubes, which give them a peculiar irregular varicose appearance, and by the fact that these peptic cells frequently contain small fat-globules, which give the extremities of the glands a dark aspect. Together with these glands, others, simple in form, seem to occur sparingly; on the other hand, true racemose glands, with arborescent ramification of the excretory duct and roundish terminal vesicles, are wholly absent, although they are met with in the last portion of the mucous membrane of the œsophagus.

The mucous glands of the stomach are found only at the pale pyloric zone; they are of the compound tubular kind, and completely resemble the above-described in their fundamental form, except that the tubes are larger in all their parts. On the other hand, *peptic cells are wholly wanting*, and even the terminal tubes of the glands, here perfectly cylindrical, are filled with short epithelium-cylinders, in which, as at the cardia, there are mostly contained fat-granules. Simple glands are absent; but, according to *Donders*, true racemose glands appear to occur, in certain cases, close to the pylorus.

In animals, as *Todd* and *Bowman* first showed in the dog, and then *Donders* and I in many other mammalia, the glands of the stomach are always of a double kind — *mucous glands* with cylindrical epithelium, and gastric glands, with cells similar to those found in man. A detailed description of some of the forms is contained in my *Micr. Anat.* ii., 2, p. 140, and *Donders* (l. c.).

To the two forms of the glands of the stomach, two differently acting secretions correspond, a fact which was first pointed out by *Wasmann*, and which has been placed beyond all doubt by myself (*Micr. Anat.* ii., 2), and also by *Donders* (l. c.). In the *dog*, as also in *ruminantia*, in the *horse*, *hare*, *cat*, and *rabbit*, glands with cylindrical epithelium are found at the pylorus, and glands with roundish cells in all the other parts of the stomach; whilst in the *pig*, the latter are found only in the middle of the stomach, especially at the large curvature. A series of experiments on artificial digestion, which I made in conjunction with *H. Goll*, of Zurich, especially on the gastric mucous membrane of the pig, clearly showed that the two kinds of glands entirely differ in respect of their solvent power; in as much as those with round cells *dissolved* acidulated coagulated protein-compounds *in a very short time*; those with cylindrical epithelium, on the contrary, either did *not operate at all, or produced a slight effect only after a longer period.* Moreover, the stomach presents a distinctly acid reaction only at the places where the former glands are situated. These observations have quite recently been confirmed, as regards the human stomach, by *Donders* and myself. The active organic material, the *pepsin*, has its seat in the roundish finely granular cells of the gastric glands, from which it can be extracted by water, particularly when it is slightly acidulated. These cells, accordingly, deserve the name *peptic cells* (*Frerichs*). The cells situated in the uppermost parts of the glands, which, as I find in man, are much smaller than the deeper ones, as if they had arisen from the latter by division, are frequently discharged externally, and are then directly concerned in the process of digestion; at other times, all, or almost all, remain in the glands during digestion, and then the fluid part of the gastric juice, which passes outwards, extracts the active material from them. The *mucus of the stomach* covers its whole surface as a thicker or thinner coating, and is commonly more strongly marked at the parts where the mucous glands are situated. It is derived—as *Todd* and *Bowman* first correctly stated (Part iii., 1847, p. 192), and, as was subsequently confirmed by *Donders* and myself — from the cylindrical cells of the surface of the stomach and interior of the mucous glands; and either exudes from them or is liberated by the dissolving and bursting of the cells, which often cover the surface of the stomach in large quantities. It is still uncertain how the epithelium is restored after the destruction of the cells, which, however, do not seem to burst within the glands themselves. Probably the epithelium-cylinders divide in the transverse direction before separation, and only the outer portion is thrown off; and, in fact, we frequently observe *two nuclei* in them. Probably, the cylinders also, as *Todd* and *Bowman* assume, discharge their mucus without becoming detached, whilst they acquire a temporary opening at the free extremity, as, in fact, is frequently observed in cast-off cells.

The stomach of birds, according to *Berlin*, contains several kinds of glands. The well-known compound tubular glands of the glandular stomach—in which a long, simple or branched central canal, with numerous simple perpendicularly arranged tubes, is closely set with cylindrical epithelium—secrete, while these cells are thrown off, a neutral juice containing pepsin. Small, simple tubes with cylindrical epithelium, situated between these peptic glands form ordinary mucus. There is a third form, lastly, in the muscular stomach, consisting of long tubes with short cylindrical epithelium, which, moreover, are covered by a structureless *tunica intima*, and whose ducts penetrate the horny epithelium of this stomach; these secrete a fluid acid juice, but no pepsin. Consequently, as *Berlin* also showed by experiments on digestion, the two chief constituents of the gastric juice are furnished by two special kinds of glands.

§ 150. The *tissue forming the mucous membrane*, exclusive of the glands, is, as we have already seen, very scanty. It appears only at the bottom of the glands as a continuous, firm, reddish layer, 0·022‴ to 0·044‴ in thickness (*Brücke*), the *muscular layer of the mucous membrane*, with interwoven bundles of ordinary areolar tissue and smooth muscular fibres, the latter of which decussate especially in two directions; and, in the pig, and as I observed recently, in man also, even pass in between the glands and into the *plicæ villosæ*. Besides, there exist between the glands, vessels, and an amorphous connective substance without elastic fibrils, which forms, upon the surface of the mucous membrane, a clear, perfectly homogeneous stratum, the structureless membrane of authors, which is connected with the *membranæ propriæ* of the individual gland-tubes, but cannot be isolated like the latter.

The whole inner surface of the stomach, from the cardia onwards, where the pavement-epithelium of the œsophagus ceases with a sharp or dentated border, possesses a simple covering of cylindrical cells, 0·01‴ in average length, which, without any intermediate layer, are directly seated upon the outermost homogeneous part of the mucous membrane. The connection of this *cylindrical epithelium*—whose other relations will be afterwards discussed in treating of the small intestine, where a perfectly similar layer exists—with the mucous membrane, is, during life, very firm, although not to such a degree that its elements, may not at times be detached, either singly or in large numbers, by mechanical influences, such as must operate in the stomach. After death, this takes place so readily, that, in man, it is only in very favourable cases that an opportunity is afforded of observing the cells *in situ*.

Besides the tubular glands, the stomach contains, although not constantly, and in very variable numbers, *closed follicles*, or the so-called *lenticular glands*, which entirely agree with the solitary glands of the small intestine—and, accordingly, need not here be further discussed—in animals (as in the pig), also small Peyerian patches.

Fig. 136.

Vessels of the large intestine of a dog, in the perpendicularly cut mucous membrane. *a*. Artery; *b*. capillary network of the surface, with the opening of the glands; *c*. vein.

The blood-vessels of the mucous membrane of the stomach are very numerous, and, in their distribution, quite characteristic; (see fig. 136, showing the vessels of the large intestine, the arrangement of which is almost entirely the same). The arteries divide in the submucous areolar tissue in such a manner that only finer vessels arrive at the mucous membrane, on which, gradually becoming finer, so as to form capillaries, they ascend perpendicularly in large numbers between the glands, and form a network of fine capillaries, 0·002‴ to 0·003‴ in diameter, surrounding the tubes, which extends as far as the openings of the glands. Here the network, which must be considered as being continuous over the whole stomach, is continued into a superficial network of somewhat wider capillaries, 0·004‴ to 0·008‴, which, in man, surround the openings of the glands in the form of polygonal meshes, 0·02‴ to 0·04‴ in diameter. This network is more developed or more simple, according to the breadth of the interglandular spaces, and the occurrence of elevations upon them, but never appears to consist of simple vascular rings. From this network the proportionally wide veins always arise by several roots, which, at greater distances from each other than the arteries, and without receiving any more blood, traverse the layers of glands, and, at the outer surface of the mucous membrane, pass into a wider network of the submucous tissue, frequently at right angles, in part horizontally. From this arrangement of the vessels, it becomes conceivable how, in the stomach, an energetic secretion (by the deeper capillaries) and an absorption (by the superficial wider networks) can take place at one and the same time.

The *lymphatics of the stomach* form, in the mucous membrane, a superficial finer, and a deep coarser network, which are perceptible only when injected. The numerous trunks passing out of the mucous membrane are readily seen in the submucous tissue, in the larger mammalia which have been killed during digestion, and their union into larger trunks, and lastly, their penetration of the muscular coat in the region of the curvature, are likewise distinctly perceptible. The nerves of the stomach, from the vagus and sympathetic, are readily traceable into the submucous tissue, and may even be seen entering the muscular layer of the mucous membrane, but are then entirely withdrawn from further investigation, which is chiefly due to the circumstance, that in the interior of the mucous membrane itself they no longer possess dark-bordered fibres, but probably only pale ones of an embryonic character.

MUCOUS MEMBRANE OF THE SMALL INTESTINE.

§ 151. The mucous membrane of the *small intestine* is thinner than that of the stomach, but more complex, seeing that, besides the tubular or Lieberkühnian glands, it presents a great number of permanent *folds* and *villi*, and contains in its tissue peculiar *closed* *follicles*, the so-called solitary and Peyerian glands, and, in the submucous tissue of the duodenum, the glands of *Brunner*.

The mucous membrane consists of a more homogeneous or indistinctly fibrous areolar tissue (especially at the innermost part) and possesses, except where certain glands are situated, but little *submucous tissue*, on which account it is pretty firmly connected with the muscular coat. Upon the inner surface of the mucous membrane theré is a *cylindrical epithelium*, of which we shall speak further when treating of the *villi*; whilst externally, towards the submucous tissue, the membrane is limited by a layer of longitudinally and transversely arranged smooth muscular fibres, discovered by *Brücke*, which, measures at the most 0·0177‴ in thickness, and on account of its being often but slightly developed, is not always readily recognisable in man.

§ 152. The *villi* of the small intestines (*villi intestinales*) are small whitish elevations of the innermost parts of the mucous membrane, visible to the naked eye, which, seated upon or between the folds of *Kerkring*, are so closely arranged throughout the whole small intestine, from the pylorus to the sharp border of the *valvula Bauhini*, as to give the mucous membrane its well-known velvet-like appearance. They are most numerous (50 to 90 in a square line) in the duodenum and jejunum, less frequent in the ileum (40 to 70 in a square line). In the duodenum they are lower and broader, like folds and laminæ, and measure $\frac{1}{10}$‴ to $\frac{1}{4}$‴ in height, $\frac{1}{4}$‴ to $\frac{1}{2}$‴, or even $\frac{3}{4}$‴ in breadth. In the jejunum, they mostly appear conical but compressed, frequently, also, leaf-shaped or cylindrical, clavate or filiform, which three last-mentioned forms preponderate in that part of the intestine. The length of these *villi* is from $\frac{1}{5}$‴ to $\frac{1}{2}$‴; the breadth, $\frac{1}{6}$‴ to $\frac{1}{10}$‴, or even $\frac{1}{24}$‴; the thickness in the flat ones, $\frac{1}{20}$‴.

The *villi* consist of an interior part, belonging to the *mucous membrane*, and an *epithelial investment*. The former, or the *villus*, in the stricter sense of the term, corresponds in its contour to the whole *villus*, and consists merely of a solid process of the proper mucous membrane, provided with blood-vessels and lymphatics and smooth muscles. Its matrix, beset with a variable number of roundish nuclei and cells, like that of the mucous membrane in general, is a more homogeneous, seldom a fibrillated areolar tissue, without any intermixture of elastic fibres, but mostly containing numerous small round cells as well as free nuclei, of which the former, in man, not unfrequently contain fat-granules, and in pathological cases, brownish or black pigment. The blood-vessels of the *villi* (fig. 137) are so numerous, that when well injected, those *villi* which are denuded of their epithelium become completely coloured; and in living or recently dead animals, each *villus*, when viewed from above, appears as a red point surrounded by a clear border. In man, every *villus* is supplied by one, two, or three small arteries, of 0·01‴ to 0·016‴ in diameter, which form a close network of capillaries, 0·003‴ to 0·005‴ wide, with round or elongated meshes, situated immediately beneath the homogeneous outermost layer of the matrix. This network mostly conveys its blood directly into the larger trunks of the submucous tissue by means of a vein, 0·022‴ in diameter, which does not arise, as in animals, by a reflexion of the artery, but generally by the gradual coalescence of the finest vessels.

Fig. 137.

Vessels of two of the *villi* of the mouse, from an injection by *Gerlach*. Magnified 45 times.

Fig. 138.

A *villus* without epithelium, with the chyle-vessel in the interior; magnified 350 times, and treated with diluted caustic soda. From the calf.

With reference to the relations of the chyle-vessels in the *villi*, I can affirm with confidence, as to man and many animals, that in many cases only a single, blind, chyle-trunk, of much larger diameter than the capillaries of the *villus*, runs in the axis of the latter (fig. 138); and I think it probable, that all the narrow *villi*, especially the cylindrical and filiform, are so circumstanced; whilst in the broad and laminated, two, or even (as *Brücke* found in the weasel and rat) three and four such trunks exist. As formerly, so now, I must, with many other authorities, express myself decidedly against the notion of a ramification of the chyle-vessels in the *villi*; and I believe that striated collections of fat in the parenchyma of the *villi* have been held for chyle-vessels; perhaps, also blood-vessels filled with dark granular particles (*Bruch*), which *Virchow*, also, has often observed.

Besides these parts, the *villi*, as *Brücke* recently discovered, contain, more towards the centre around the lymphatic vessels, a thin layer of longitudinal *smooth muscular fibres*, with very delicate narrow fibre-cells, which, in favourable cases, are very distinct even in man, and, as I find, are continued down between the Lieberkühnian glands, and connected with the muscular layer of the mucous membrane. They occasion the shortening or contraction of the *villi* discovered by *Lacauchie*, which is very evident immediately after death (fig. 139), and, according to *Brücke*, is also perceptible in living creatures, and which very probably exerts an important influence upon the further movement of the chyle and venous blood in the *villi*, that is, supposing there is no reason against the assumption of repeated contractions during life. No nervous elements are known to exist in the *villi*; but the walls of the intestine are rich in nerves, and even contain, as

Fig. 139.

An intestinal *villus* of the cat, in the act of contraction. Magnified 60 times.

Fig. 140.

A. Two *villi*, with their epithelium, from the rabbit, magnified 73 times. *a*. Epithelium; *b*. parenchyma of the villus. *B*. A detached sheet of epithelium, magnified 300 times. *a*. Membrane raised up by the action of water. *C*. Single epithelial cells, magnified 350 times. *a*. with, *b*. without, a raised-up membrane; *c*. a few cells from the surface.

Meissner discovered [illegible] in the submucous layer, a great number of microscopic ganglia. Similar ganglia also occur in the stomach and the large intestine.

§ 153. The *epithelium of the* [illegible]lli and of the surface of the mucous membrane, although, during [illegible]fe, very intimately connected with the subjacent parts, and falling off only through accident or disease, is readily detached in the dead body, and is perceptible only upon perfectly fresh portions of the intestine. It everywhere consists of a simple layer of cylindrical cells, slightly narrowed at the lower end, 0·01‴ to 0·012‴ in length, 0·003‴ to 0·004‴ in breadth, which have a clear, vesicular, oval, single or double, nucleolated nucleus, but generally contain nothing else except fine granules. These cells, which agree in all their chemical characters with the deeper cells of the epithelium of the oral cavity, are so intimately connected together, that even after death their contours, when viewed in a longitudinal section, are at first not at all or only indistinctly recognisable; whilst they appear as a beautiful mosaic structure, when viewed from the surface. Properly speaking, the cylindrical cells become first quite distinct when they are detached from the subjacent surface, which generally takes place in such a manner that they come off in patches, or even all the cells of a *villus* together, like the calyptra of a moss.

I have recently shown (*Würzburg Transactions*, vi., 1855) that the membranes of these cells are *thickened* and *very finely striated* at their free surface, and that these thickened parts represent, as it were, in their totality, a special membrane covering the cells, similar to the cuticula of plants. By the influence of water, the cells are dilated into long, pyriform, clear vesicles, or burst at the free extremity, and allow their contained mucus to pass as a clear globule, which frequently carries the nucleus along with it. The mucus, which covers the surface of the intestine in the dead body, is, in great part, nothing but the transuded contents of the epithelial cells. By the absorption of water, it swells up in form of a thick crust, and always contains numerous ruptured and empty cell-envelopes.

The normal secretion of the mucus in the small intestine is effected exactly as in the stomach, except that the cells never fall off, and appear usually to discharge their mucus without bursting.

Brücke affirms, that the central chyle-vessel of the *villi* is a space without bounding walls, and that interstitial depositions of chyle also take place in other parts of the mucous membrane, and are then conveyed onwards into the true chyle-vessels. I, on the other hand, hold that the chyle-trunk of the *villus* possesses a membrane, which I have distinctly seen, and believe that *Brücke* has been led to his view, more from theoretical considerations than from direct facts. Similar considerations have induced this author to assert, that the epithelial cylindrical cells of the *villi* are completely destitute of a membrane at their broader extremity, and have orifices at the part turned towards the *villus*, to which similar openings in the limiting membrane of the *villus* itself correspond. *Brücke* himself admits that the two last-mentioned openings cannot be directly observed, so that I shall content myself with remarking, that, according to my most recent investigations (l.i.c.), there can be no doubt as to the existence of a membrane on the free extremity of the cells. By *Brücke's* view, the difficulties which present themselves in explaining the absorption of fat, would, undoubtedly, be easily removed, if apertures were demonstrated to exist everywhere; but this can furnish no reason to disregard undoubted facts. In the *absorption of fat*, as *Goodsir*, and *Gruby* and *Delafond* have shown, the cylindrical epithelial cells, — frequently on the whole of the *villus*, but often only on the apex (because the *villi*, when they are distended and the intestine is contracted, frequently lie so close to each other, that only their apices are accessible to the intestinal contents) — become filled with fine fat-granules or larger fat-drops, but how, is still undetermined.

According to the most recent investigations of *Brücke* and myself, the fat, before its absorption, divides into molecules of immeasurable fineness, and it is taken up only in this form by the epithelial cells. Now, since I have shown that these cells possess a distinct and even thickened membrane upon their surface which is directed to the intestinal canal, we are compelled to assume, that the fat-molecules pass through this membrane, either by preformed canals or pores, or by making a way for themselves through the substance of the membrane. With regard to the existence of pore-canals in the cell-membranes in question, I refer the reader to my treatise cited above, and remark here only this much, that it is very possible, that the striæ discovered by me in the cell-wall are to be attributed to extremely fine canals. At any rate, these striæ point to a quite peculiar structure of the absorbing cell-walls, and deserve, accordingly, a special consideration on the part of physiologists. I may add, that the thickened striated cell-wall swells up in water, and suffers a peculiar splitting, so that it gradually becomes similar to a bundle of short fibrils or cilia. Such epithelial cells were incorrectly described, a considerable time ago, by *Gruby* and *Delafond*, as ciliated epithelium of the intestine. *Donders* and I have found that the cylindrical cells of the intestine not unfrequently burst at their apices, and allow a part of their contents (mucus) and their nucleus to pass out. A second, previously formed cell-nucleus then serves for the regeneration of these cells, which, in this stage, possess opaque, often granular, contents, and clavate forms: these are the cells designated by *Gruby* and *Delafond* 'epithelium capitatum.'

In the parenchyma of the *villi*, there are found at the apices frequently one or more large globules of firm and of fluid fat, which, according to *Donders*, arise from a separation of the fat which has penetrated taking place after death. The smaller cells, described by *E. H. Weber* as being under the epithelial cells, have no existence.

§ 154. *Glands of the small Intestine.*—The small intestine contains only two kinds of true glands, viz., 1. *tubular*, which exist everywhere in the mucous membrane; and 2, *racemose*, seated in the submucous tissue.

The *racemose*, or the glands of *Brunner*, form, at the commencement of the duodenum, on the outer side of the mucous membrane, a continuous glandular layer, which is most developed and dense close to the pylorus, so that here they give rise to a glandular ring, which extends as far as the opening of the gall-duct. If, in a distended duodenum, the two layers of the muscular coat have been dissected off, the glands are readily recognised as yellowish, rounded angular, flattened bodies, $\frac{1}{18}'''$ to $1\frac{1}{2}'''$, or, on an average, $\frac{1}{4}'''$ to $\frac{1}{2}'''$ in diameter, which, enveloped in some areolar tissue, are seated close to the mucous membrane, and send off short excretory ducts into it. With reference to their intimate structure, the glands of *Brunner*, whose terminal vesicles measure 0·03''' to 0·06''', or even 0·08''' in diameter, entirely agree with the racemose glands of the oral cavity and œsophagus. Their secretion is an alkaline mucus, without morphological elements, which exerts no digestive action upon coagulated protein compounds, and probably subserves mere mechanical purposes.

Fig. 141.

Lieberkühnian glands of the pig; magnified 60 times. a, *membrana propria* and epithelium; b, cavity.

The *tubular* or *Lieberkühnian glands* are found distributed over the whole small intestine and duodenum as very numerous, straight and narrow tubes, extending through the entire thickness of the mucous membrane. At the extremity they are slightly swollen, but very seldom bifurcated (but in animals, they are frequently bifid or trifid). An idea of their number may be best obtained when the mucous membrane is examined in perpendicular sections, or from above, by low magnifying powers. In the first case, we see tube upon tube, almost without any interspaces, arranged closely together like palisades (fig. 141); in the latter, we perceive that the glands do not exist everywhere, but occupy only the interspaces between the villi, though they are here present in such numbers that they, so to speak, leave no further space remaining; and the surface of the mucous membrane between the villi appears perforated and cribriform. Such glands are found even upon the Peyerian patches and the solitary follicles, but in man they leave the part of the mucous membrane, which lies immediately over the middle of the follicle, free, and are arranged, accordingly, more in the form of rings around the follicles. The length of the Lieberkühnian glands is equal to the thickness of the mucous membrane, and varies from $\frac{1}{5}'''$ to $\frac{1}{7}'''$; their breadth measures 0·028‴ to 0·036‴; and their opening 0·02‴ to 0·03‴. They consist of a homogeneous *membrana propria* and a cylindrical epithelium, like that of the intestine, which, during the formation of chyle, never contains fat, and which, during life, distinctly encloses a cavity filled with a clear fluid secretion, the *intestinal juice*, as it is termed; but after death, and on the addition of water, it is very readily altered, the glands appearing to be completely filled with cells or with a granular substance.

The *vessels* of the Brunnerian glands present quite the same conditions as those of the salivary glands; whilst those of the Lieberkühnian tubes accurately conform to the type of those of the stomach (see § 136).

In the intestinal mucus, *one-nucleated, small, round cells* are not unfrequently met with, the origin of which is doubtful. In different diseases, especially of the intestine,—in inflammation, peritonitis, in typhus,—*Böhm* found in many Lieberkühnian glands a whitish viscid secretion (*Gland. int.*, p. 34), which, as subsequent observations of the same author (*Darmschleimhaut in der Cholera,* p. 63) lead us to suppose, was nothing else than the epithelium which had detached itself from the walls, and collected in form of a compact plug. In the cholera, this epithelium, as well as that of the whole intestine, is, according to *Böhm*, thrown off.

§ 155. *Closed Follicles of the small Intestine.*—In the walls of the small intestine, there are met with, singly or in groups, vesicles of a peculiar kind, whose anatomical as well as physiological signification is still not quite cleared up, and which, accordingly, may, for the present, be most conveniently described under a general name.

The most important of them are the collections or *patches of Peyer* (*glandulæ Peyerianæ sive agminatæ*). They mostly occur in form of oblong or roundish flattened organs, which are arranged in the longitudinal direction, invariably on the border of the intestine opposite to the attachment of the mesentery. They are best seen from within, and appear as not very distinctly circumscribed, slightly depressed and smooth patches. But even from without they may be recognised, by a slight elevation of the intestinal wall, and, by transmitted light, look like opaque parts of the membrane. The *seat* of these collections is, in most cases, the ileum; still they are not unfrequently met with in the lower part of the jejunum, occasionally in its upper half near to the duodenum, and even in the horizontal inferior part of the duodenum. In ordinary cases, their number is 20 to 30; when they are met with also higher up they increase to 50 or 60; but they are always most close to one another in the lowest part of the ileum. The *size* of the patches is usually larger the nearer they are to the cœcum; and their length mostly amounts to from 5‴ to 1½ in., but may be only 3‴, or increase to 3 or 5 in., or even 1 ft., whilst their breadth measures 3‴, 5‴ to 9‴. The folds of *Kerkring* are usually interrupted wherever Peyerian patches are situated; still, in the jejunum, folds are found also upon the patches, and, in the ileum, instead of them, frequently rows of closely set villi. When more narrowly examined, each Peyerian collection is found to be *an aggregation of closed follicles*, which have a roundish shape, or are somewhat conical and tapering towards the cavity of the intestine, $\frac{1}{6}$‴ to $\frac{1}{2}$‴ to 1‴ in size. The follicles lie close to each other, have their seat partly in the mucous membrane itself, partly in the submucous tissue, and, on the one side, are distant only 0·02‴ to 0·03‴ from the surface of the mucous membrane; whilst, on the other, they immediately adjoin the muscular coat,

Fig. 142.

A human Peyerian collection; magnified 4 times. *a*. Surface of the ordinary mucous membrane, with villi; *b*. depressions upon the patch corresponding to the follicles; *c*. intermediate substance with small villi.

which is here somewhat more firmly adherent to the mucous membrane.

When viewed from the cavity of the intestine, the patches present, very conspicuously in man, numerous small depressions, $\frac{1}{3}'''$ to $\frac{1}{2}'''$ to 1''' apart from each other. These depressions correspond to the individual follicles, and their bottom is slightly protruded upwards by the latter, but they never support any villi. The remaining portion of the patch is occupied by *ordinary villi*, or reticulated folds, and apertures of Lieberkühnian glands, which latter are arranged in a circlet, of 6 to 10 and more apertures, around the slight elevations occasioned by the follicles, the *corona tubulorum* of authors.

Fig. 143.

A particle of a Peyerian gland, from an old man; after *Flouch.* *a.* Follicles surrounded by the openings of the Lieberkühnian glands; *b.* villi; *c.* more isolated openings of Lieberkühnian glands.

Every follicle of a patch consists of a *completely closed*, thick, tolerably firm *envelope* of an indistinctly fibrous areolar tissue with interspersed nuclei, and soft, mostly greyish (never milk-white) contents, which are slowly diffusable in water, and composed of a certain amount of *fluid* and innumerable nuclei and round cells, 0·004''' to 0·008''' in diameter. These cells, when recent, appear perfectly homogeneous and dull grey; they become clear on the addition of water or acetic acid, and then disappear; whilst the nuclei become, at the same time, granular, and come very distinctly into view. Amongst these elements, which also occasionally contain fat in the form of granules, and, as shown by comparison of the different forms, are continually undergoing the process of formation and dissolution, there exist, as *Frei* and *Ernst* have discovered in animals, and as I have found also in man, numerous but very fine blood-vessels, 0·0015''' to 0·004''' in diameter, which are connected with a rich vascular network surrounding the follicle, and in animals, as *e.g.* the pig, can even be recognised with facility in

Fig. 144.

Horizontal section from the middle of three Peyerian capsules of the rabbit, to show the vessels in their interior. After an injection of *Frei.*

the contents of the follicles when perfectly fresh and carefully extracted.

But little is accurately known about the *lymphatic vessels* of the Peyerian glands. This much is established, *that the number of the chyle-vessels coming from the Peyerian patches during the period of digestion is greater than at other parts of the intestine*, although the villi found upon them are less developed and more scanty; but it is entirely unknown how the chyle-vessels are arranged in the interior. It appears probable, that they form networks around the individual follicles—at least, we see from the outside that they surround the follicles in a circular manner; on the other hand, they do not enter into the follicles, at least on this surface, which entrance would be readily recognised by the milk-white colour of the filled vessels. For this reason, if, as *Brücke* has recently assumed, a direct communication of the follicles with lymphatic vessels exists, it can take place only by the follicles becoming connected with such vessels upon the surface opposite to the cavity of the intestine.

The solitary glands *(glandulæ solitariæ)* agree so completely with the individual elements of the Peyerian patches in size, contents, and structure, and in respect of the vessels in their interior, which I also observed even in man, that a separation of them is by no means justifiable; especially too as all possible variations are found in the number of the follicles and since, at least in animals, there occur Peyerian patches with 2, 3 to 5 follicles. In man, the number of the solitary glands, as all authors correctly state, is extremely various; sometimes we do not succeed in finding a single one, sometimes the intestine is quite overstrewn with them, as far as the border of the ileo-colic valve, or, finally, they are found in the ileum and jejunum in moderate number. Their complete absence may, perhaps, be regarded as an abnormal condition, since, in newly-born infants and in the dead bodies of healthy individuals, they are constantly present, and, indeed, more numerously in the jejunum than in the ileum; on the other hand, the millet-seed-like vesicles, which, in catarrh of the alimentary tract, are often found in immense numbers in the small intestine and stomach, may have either partially or completely a pathological signification, since, in other organs also (as in the liver, according to *Virchow*), the occurrence of similar follicles has been demonstrated. The solitary follicles are embedded in the same way as the elements of the patches, only they occur also upon the mesenterial border, and support villi, upon the most prominent part of their intestinal surface.

I consider it as quite established that the follicles of the Peyerian patches have no openings, but will, however, notice the following points:—1. In animals examined immediately after death, the capsules are invariably found closed, as may be very readily seen on the well-developed *patches* of the pig, sheep, cat, dog, etc, which I may recommend in general for the investigation of these organs, because the *patches* in man are so frequently altered. 2. An appearance of openings may arise from the depressions of the mucous membrane over the individual follicles, especially when the prominent part of the wall of the follicle is not much distended. 3. In man, the closed follicles are subject to manifold diseased conditions, and they are frequently found ruptured and altered, so that often nothing remains of the patches but a reticulated, indistinctly pitted surface; moreover, they may, as *Virchow* first showed, burst after death, when they are allowed to lie in water in a warm place, on which account, perhaps, many of the apertures found in dead bodies must be regarded as having been produced by putrefaction.

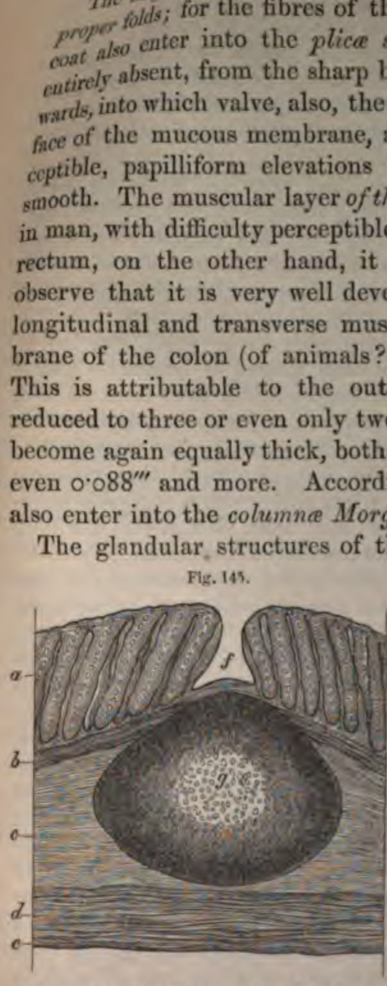
The connection of the Peyerian follicles with chyle-vessels, asserted by *Brücke*, from which these organs have been viewed as lymphatic glands, deserves, at any rate, to be duly considered; still I must here, as with reference to many other subjects, take upon myself the somewhat ungrateful task of warning against too hasty conclusions. An unprejudiced consideration of the facts at present known does not warrant the conclusion, that the direct transition of the follicles into chyle-vessels, as *Brücke* maintained at first, has been proved (see my *Micr. Anat.*, II. 2, p. 188), nor that, as *Brücke* now assumes, there exist in the interior of the follicles interstitial chyle-spaces, which lie between their vessels, and lead externally to true lymphatic vessels upon the follicles. That there is a difference between the Peyerian patches and the lymphatic glands cannot be denied. In the latter, the alveoli communicate directly with one another; whilst in the former, the follicles are almost always completely closed vesicles (communications of individual follicles, as were observed by *Henle* and *Brücke*, are certainly very rare; I likewise never saw them destitute of a wall at any side); further, the lymphatic glands have afferent and efferent chyle-vessels, whilst on the patches of *Peyer*, only the latter are known; lastly, the alveoli of the glands, as I must remark, in contradiction to *Brücke*, are also found filled with chyle, whilst in the follicles, no one has, hitherto, seen anything of the kind. Nevertheless, I will not altogether dispute *Brücke's* view of the signification of the patches of *Peyer*; and I would call upon observers to investigate whether lymphatic vessels exist in the interior of the follicles, and whether, as I have seen in one case (*Zeitschr. f. wiss. Zool.*), the chyle-vessels coming from the patches are richer in chyle-cells than those proceeding from other places of the intestine, which, if confirmed, would, in my opinion, be sufficient in warranting us to regard these organs as formative centres of the lymph-corpuscles.

§ 156. *Mucous Membrane of the Large Intestine.*—The large and small intestines agree in the structure of their mucous membrane in so many essential characters, that it will suffice to call attention to some few points of difference.

The large intestine, with the exception of the rectum, has no proper folds; for the fibres of the transverse layer of the muscular coat also enter into the *plicæ sigmoideæ*. The villi are likewise entirely absent, from the sharp border of the *valvulæ Bauhini* onwards, into which valve, also, the muscular coat enters; and the surface of the mucous membrane, apart from the small, scarcely perceptible, papilliform elevations at particular places, is even and smooth. The muscular layer *of the mucous membrane* of the colon is, in man, with difficulty perceptible, but is decidedly present; in the rectum, on the other hand, it is more distinct. In animals, I observe that it is very well developed. According to *Brücke*, the longitudinal and transverse muscular layers of the mucous membrane of the colon (of animals?) are together only 0·013‴ thick. This is attributable to the outer longitudinal fibres, which are reduced to three or even only two strata; in the rectum, the layers become again equally thick, both together about 0·022‴, at the anus even 0·088‴ and more. According to *Treitz*, the muscular fibres also enter into the *columnæ Morgagnii*.

The glandular structures of the large intestine are the *Lieberkühnian glands* and *solitary follicles*. The former, also called *glands of the large intestine*, are found everywhere, from the Bauhinian valve as far as the anus, and also in the *appendix vermiformis*, closely crowded together. They present entirely the same structure as those of the small intestine, only they are longer and broader ($\frac{1}{4}$‴ to $\frac{1}{5}$‴ in length, $\frac{1}{12}$‴ to $\frac{1}{20}$‴ in breadth), in conformity with the greater thickness of the mucous membrane. Here, also, in man and in animals, I observed throughout in the fresh condition no morphological elements, except a

Fig. 145.



Solitary follicle from the colon of a child; magnified 45 times. *a.* Tubular glands; *b.* muscular layer of the mucous membrane; *c.* submucous tissue; *d.* transverse muscular fibres: *e.* serous membrane; *f.* depression of the mucous membrane over the follicle *g.*

beautiful cylindrical epithelium. In the *vermiform appendix*, the *solitary follicles* are arranged close to each other; they are very frequent in the cœcum and rectum, and are also more numerous in the colon than in the small intestine. From those of the latter part they are distinguished by their more considerable size ($\frac{3}{4}'''$, $1'''$ to $1\frac{1}{2}'''$), and by the circumstance, that upon each of the small elevations of the mucous membrane which are occasioned by the follicles, there exists, in the middle, a small pit-like, elongated, or round opening, $\frac{1}{9}'''$ to $\frac{1}{12}'''$ in diameter, which leads to a small depression of the mucous membrane over the follicle. *Böhm* had in his time allowed himself to be misled by these depressions, which are never present upon normal follicles of the small intestine, and regarded the follicles as follicular glands with openings, which, however, is incorrect; for at the bottom of this depression there lies, as *Brücke* also observes, a completely shut, somewhat flat capsule, of exactly the same structure as the follicles in the small intestine, and also with vessels in the interior, as I recently found likewise in man.

The blood-vessels of the glands and follicles of the large intestine present the same conditions as in the small intestine. Around each Lieberkühnian opening there is a ring formed of vessels $0{\cdot}006'''$ to $0{\cdot}01'''$ in diameter, which is sometimes simple, sometimes, especially in the neighbourhood of the solitary capsules, multiple. From these vessels, wider venous trunks arise, which pass inwards between the glands; whilst finer capillaries, arising immediately from the arteries, form a dense network around these (fig. 136). The relations of the *lymphatics* in the mucous membrane are wholly unknown, as also those of the nerves. The epithelium presents, throughout, the same conditions as in the small intestine, and, at the anus, is marked off from the external epidermis by a tolerably sharp border.

§ 157. *Development of the Intestinal Canal.*—The *whole intestinal wall*, however different it may subsequently appear, arises from two formative parts, viz., 1. from the lower *germinal lamina* (mucous lamina, *Pander-Baer*; mucous membrane, *Reichert*; glandular lamina, or intestinal gland-lamina, *Remak*), which is not the basis of the entire mucus membrane, but only that of the intestinal epithelium, and the intestinal glands; and 2. from the middle *germinal lamina* (vascular lamina, *Pander*; membrana intermedia, *Reichert*), which, besides many other parts (muscles, bones, nerves, heart), also furnishes the muscular coat of the intestine, as well as the vessels, nerves and investments of the intestinal glands.

At the commencement, and for some time after, the inner layer, or the *epithelial tube*, consists merely of cells; and, by their continued multiplication both in the area and thickness of the membrane—and effected, according to *Kremak*, by division,—it becomes converted, first, into the subsequent epithelium, and, secondly, into the *glands* of the intestine. Of the latter, the Lieberkühnian glands of the small intestine are, from the commencement, hollow recesses of the epithelium; whilst the salivary and the Brunnerian glands, like the sudoriparous glands, are solid processes of the epithelium, and acquire their cavities when they become further ramified. The glands of the stomach and large intestine also certainly arise from the primitive epithelial tube, whether as inversions or solid growths is still undetermined, and form, at first, a layer which is completely separated from the fibrous layer of the intestine, and, consequently, the epithelium, upon these places, appears much thicker than subsequently. Afterwards, delicate vascular processes grow inwards from the fibrous layer between the glands, till at length both layers, becoming intimately connected, represent the proper mucous membrane. Similar and still more considerable outgrowths of the fibrous layer form the villi, whilst from its outer parts the muscular and serous coats are developed.

The *investigation* of the intestinal mucous membrane presents greater obstacles than that of other parts. The epithelium is generally found well preserved only in perfectly fresh specimens, and, for the most part, readily disintegrates into its elements. The villi are best seen in thin perpendicular sections made with fine scissors, and examined with low magnifying powers by reflected light. During the process of absorption, they are mostly found filled with fat and nuclei, so that their several parts are imperceptible, with the exception of the chyle-vessels, which become distinct by the addition of acetic acid, or still better of diluted caustic soda. At other times, the muscles of the villi are easily recognised by their nuclei when acetic acid is added. To study the blood-vessels, injections must be employed, especially usch as have been made contemporaneously from the arteries and veins, and are preserved in moist condition (still, the vessels of the villi are readily seen, even in perfectly fresh objects). The same applies to the other parts of the intestine, in which perpendicular sections are especially instructive. For the glands, I employ fresh pieces of intestine, although the preparation of such is frequently, as in the stomach, extremely difficult; also, such as have been hardened in absolute alcohol, wood-vinegar, or chromic acid; further, mucous membrane boiled with acetic acid of 80 per cent. and dried (*Purkinje* and *Middeldorpf*), or saturated with gum and dried (*Wasmann*), of which thin perpendicular and transverse sections are to be made with a sharp knife, and which, if requisite, may be rendered clear by the addition of a little caustic soda. The separation of the mucous membrane into its elements is most difficult, especially when it is thick, as in the horse and pig. This is easier in the dog, cat, and rabbit, and in the ruminants, in which, when the back of the knife is carried over the mucous membrane at the same time strongly pressing, the epithelium of the glands is frequently extracted in continuity, which, of course, gives all the information that could be desired concerning the form and the lining of the glands. Moreover, the mucous membrane of the stomach of the last-mentioned animals readily breaks up into its elements by simple teasing out.

The glands of *Brunner* occasion no difficulties except as to their excretory ducts, which, however, are distinctly seen in perpendicular sections, and in animals, also, when the mucous membrane is teased out. The Lieberkühnian glands may likewise be very readily isolated in their entire length; whilst the closed follicles of the intestine are to be carefully exposed from without, to be isolated or pricked, and also to be studied upon perpendicular sections. The muscular layer of the mucous membrane is likewise to be exposed from without by the detachment of the *tunica nervea*, and then to be detached in small segments from the glandular layer; its elements are very well seen after maceration in nitric acid of 20 per cent.

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V.—OF THE LIVER.

§ 158. The liver is a large gland, which is distinguished from the compound glands, hitherto described, such as the salivary, even by the intimate connection of its larger subdivisions, and is altogether peculiar in respect of the structure of the secerning parenchyma, which prepares the gall. The parts which constitute and belong to it are — the secreting parenchyma, consisting of the lobules of the liver and the networks of the hepatic cells; the biliary passages which are formed in this, and the efferent bile-ducts; very numerous blood-vessels; a considerable number of lymphatics and nerves; lastly, a covering of peritoneum.

§ 159. *Secreting Parenchyma, Hepatic Lobules, and Hepatic Substance.*—If the natural surface or a section of the human liver be examined, it usually presents a spotted appearance, and mostly in such a manner, that small red or brown spots, of a stellate shape, are surrounded by a more yellowish-red substance—medullary and cortical substance (*Ferrein*)—which colouring arises only from the usually unequal distribution of the blood in the small vessels and capillaries; and, in quite fresh and healthy livers, gives place to a uniform reddish-brown colour. The *human* liver, as *E. H. Weber*, 1842, first showed, has no insulated lobules, to the assumption of which the often regularly spotted appearance has led; and so much the more, as they are found very well marked in an animal often submitted to investigation — the pig; but in man, the secerning apparatus, as well as the most important parts of the vascular system, *i.e.*, the capillary networks, situated between the portal and hepatic veins, are most intimately connected throughout the whole liver. Nevertheless, we should be very much mistaken, if we were to regard the secerning hepatic parenchyma as being everywhere uniform. There exist in it certain ultimate divisions, which, although by no means insulated from each other, still possess a certain independence. These *hepatic lobules*, as they may still be called, when the word is understood in a less strict sense, or hepatic islets (*Arnold*), arise in the following way, viz., 1, the smallest trunks of the efferent and afferent blood-vessels, the venæ inter- and intra-lobulares (*Kiernan*) are distributed at pretty equal distances through the whole liver, so that a piece of hepatic substance, of $\frac{1}{3}'''$, $\frac{1}{2}'''$ to $1'''$ in diameter, invariably gives origin in its interior to a small root of the hepatic vein, and receives from without, *i.e.*, at its circumference, a certain number of the finest branches of the portal veins and hepatic artery; 2, the commencement, also, of the excretory canals or hepatic ducts are not irregularly scattered in the parenchyma, but are so arranged that they always begin at a distance of $\frac{1}{7}'''$ to $\frac{1}{3}'''$ from the commencement of the hepatic veins, and run with the finest branches of the portal veins. There thus arise small segments in the liver, which contain only secerning parenchyma, capillaries, and the commencements of the hepatic veins; whilst in their interspaces, together with the parenchyma and the capillaries, there exist, also, the commencements of the hepatic ducts and the ultimate branches of the portal vein and hepatic artery, which, while they pass into these segments, not only from one, but always from several different sides, and are strengthened and, in part, united by areolar tissue, form, if not complete, at least partial zones around them.

The livers of animals which present lobules (pig, polar bear, *J. Müller;* Octodon Cummingii, *Hyrtl*) are of the greatest importance for the knowledge of the structure of this organ, and I may give here, accordingly, a description of the structure of the pig's liver. If such a liver be examined on sections or otherwise, it is always found divided into numerous small, roundish, polygonal, not quite regular, spaces of tolerably uniform size ($\frac{1}{2}'''$ to $1\frac{1}{4}'''$), which consist of the proper liver-parenchyma, and are separated by whitish partitions readily visible to the naked eye. If the cut surface be scraped with the handle of the scalpel, angular portions of the liver, of the same size as the spaces, become separated, and the capsules which surround them remain behind as empty compartments, like a honeycomb. The latter appear still more distinctly when a thin segment of the liver is lightly kneaded in water with the fingers, then washed, and viewed on a black ground, in which case many compartments remain almost completely closed, and thus present themselves still more distinctly as complete capsules. These capsules, however, are not to be understood as if every hepatic lobule possessed its special envelope; but the membranes, which form them, rather belong always to several lobules in common, so that the whole presents a *connected* trellis-work, whose partitions are all simple, and cannot

Fig. 146.

Section of the liver of the pig, with an opened hepatic vein; slightly magnified. *a.* Large vein, into which no intralobular veins open; *b.* branches of the same with intralobular veins, and the bases of the lobules visible through them. After *Kiernan.*

be divided into several distinct lamellæ. If the capsules, or, as they might be still better called, the *septa* of the lobules, be followed, it is found that they are chiefly expansions of the areolar tissue accompanying the *vena portæ*, etc., or of the so-called capsule of *Glisson*, although they are also connected with the serous covering of the liver, and adjoin the larger hepatic veins. *Kiernan* was the first to comprehend and express correctly the relation of the lobules to the hepatic vessels, when he said, that they sit upon the branches of the hepatic veins like leaves upon their stalks. In fact, it is found, when a smaller branch of the hepatic vein is cut open (fig. 146, *b b*), that it is surrounded on all sides by hepatic lobules, and receives a vein from each of them, so that they really appear to be attached to it by short stalks.

Now, since the same arrangement exists in the veins of medium diameter downwards, as far as the venæ intralobulares, the hepatic veins and lobules may, not without reason, be compared to a tree, whose branches are so numerously and closely beset with polygonal leaves, that the foliage, so to speak, constitutes only one mass. If, now, it be imagined that another ramified vascular system is interpolated from above into the tree of hepatic veins, so that its larger branches penetrate into the clefts between the main divisions, and the smaller and smallest into the interstices of the subordinate segments and the lobule, and in such a manner, that each lobule is on many of its sides in contact with the finest branches, and receives a coat from the connective tissue accompanying them, we have obtained as definite an idea as is possible of the relations of the portal vein. With regard to the gall-ducts and the hepatic arteries, they simply accompany the portal vein, and require, accordingly, no further mention. The *form of the lobules* is, in the pig's liver, angular, so that, when viewed in longitudinal and transverse sections, they generally form irregular four, five, or six-sided figures.

Fig. 147.

Branch of the portal vein of the pig cut open, with the branches of the hepatic artery and duct accompanying it. After *Kiernan*.

In the human liver, the connective tissue accompanying the vena portæ between the hepatic islets, is very scanty, and there are neither sheaths around the individual islets, nor any complete enclosure of them by the vessels. In *cirrhosis hepatis,* on the other hand, the connective tissue of the liver-parenchyma increases excessively, and the individual secerning segments may then appear more distinctly, or be quite separated into true lobules. The reddish-brown hepatic substance is softer, because it is more macerated, and sinks in at the surface and upon sections more than the rest; it can also be more readily scraped away, and in fine sections falls out from the surrounding structure with facility. The cortical substance, which surrounds, in a reticulated manner, the reddish-brown spots, presents narrower portions *(fissuræ interlobulares, Kiernan),* and broader angular ones *(spatia interlobularia),* in which a red point, occasioned by a branch of the portal vein, may not unfrequently be seen, yet not so regularly as in the brown places, where it arises from the *vena intralobularis,* and frequently appears star-shaped. From the greater congestion of the capillary network, it may happen, and, according to *Theile,* this is the rule in the majority of healthy human livers, that the *fissuræ interlobulares* disappear, and the brown substance appears in the form of a network, and the yellow in that of isolated spots. I find that, as already mentioned, perfectly fresh livers are mostly coloured uniformly. *Kiernan* describes, in the liver of children, a reversal of the colouring, which he attributes to a congested state of the vena portæ, so that the outer parts of the hepatic lobules are more injected. Neither *Theile* nor I have directed our attention to this form.*

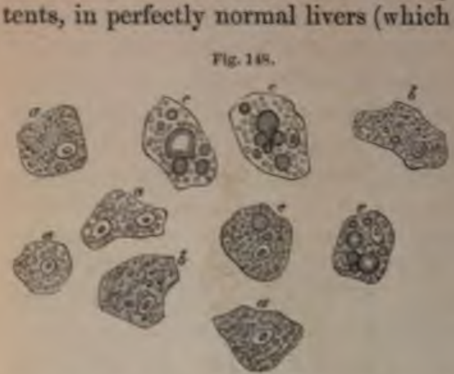
§ 160. *Hepatic Cells and Hepatic Cell Networks.*—Each *hepatic islet* contains two elements: 1. a *network of capillaries,* which is connected, on the one hand, with the finest branches of the portal vein, and on the other, collects its blood into its central vein, one of the commencements of the hepatic veins; and 2. a *meshwork of delicate trabeculæ,* which consist solely of cells closely and continuously joined to one another, the *hepatic cells,* as they are termed. These two networks are so interwoven with one another, that the interspaces of the one *are completely filled up* by the parts of the other; and there exist, at least when the vessels

* According to *L. Beale,* the lobules of the liver of the pig are each provided with a separate fibrous capsule of its own, so that each partition between two lobules would be formed by two membranes, united by connective tissue.

are injected or contain blood, no interspaces between them. No trace of *canals* containing bile is to be seen in this network, and these first appear in the periphery of the hepatic islets at the place where the finest branches of the portal vein are situated.

The hepatic cells, measuring 0·008‴ to 0·012‴ in diameter, on an average, and 0·006‴ to 0·016‴ in extreme instances, become isolated with the greatest facility, and resemble in their form the elements of pavement epithelium, only their shape is more irregular. Their membrane is delicate and completely closed, and their contents, in perfectly normal livers (which is seldom the case in man), consist,—besides a round, vesicular nucleus, 0·003‴ to 0·004‴ in size, and a nucleolus, double in many cells,—of a finely granular, slightly yellowish and semi-fluid substance, which, as microscopical examination shows, probably contains the essential elements of the bile. Moreover, there are frequently met with fat-drops and yellow *pigment granules*. The former are present (fig. 148, *c*), in fatty degeneration of the liver, in all the hepatic cells, and in such abundance, that these become very like certain forms of fat-cells. The fat generally completely fills the cells in form of few larger or numerous smaller drops, so that the nucleus becomes invisible. Every transition occurs from these well-pronounced forms to the ordinary cells with some few small globules: and, indeed, cells containing a moderate quantity of fat, occur in a certain number in almost every dead body which is examined; so that, but for the knowledge that these fat-globules are entirely absent in animals, the phenomenon might, at least in its slighter grades, be considered as quite normal. Almost the same holds good as to the pigment granules (fig. 148, *b*). They also, when they appear in large quantities, are certainly abnormal; but, on the other hand they may, when more scanty, be regarded as only a slight deviation from the physiological condition. They are small, scarcely exceeding 0·001‴ in diameter, yellow or yellowish-brown, and behave towards re-agents exactly as the colouring matter of the bile deposited within the intestinal canal, seeing that they

Fig. 148.

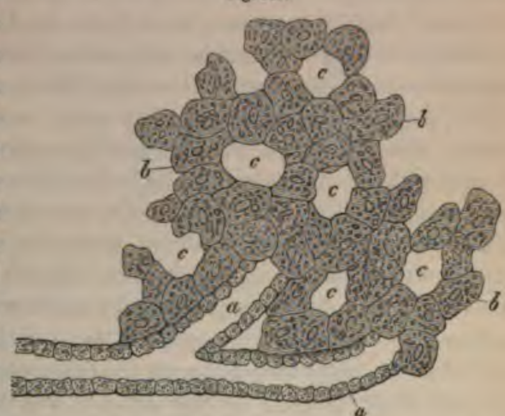


Hepatic cells of man; magnified 400 times. *a*. Normal cells; *b*. with coloured granules; *c*. with fat.

undergo no change of colour on the addition of nitric acid, and do not dissolve in caustic alkalies.

The hepatic cells are so arranged in the hepatic islets as to form longer or shorter *columns*, which unite by short lateral anastomoses, and form in this manner a close network. The simple or branched rows of hepatic cells, which are always met with among the scraped-off particles of the liver, are nothing else than *fragments* of this hepatic cell-network, whose elements are not very firmly connected. Considered as a whole, the network of each hepatic lobule presents, at the periphery, roundish meshes; in the centre, on the other hand, always a radiated arrangement, and in such a manner, that in transverse sections, passing through the central vein, elongated and ramified trabeculæ of hepatic cells appear to spread out from the latter, with small lateral anastomoses towards all sides, the meshes between them appearing as long narrow fissures.

Fig. 149.



Network of hepatic cells, of man; magnified 350 times. *a.* Spaces for the vessels; *b.* hepatic cells; *c.* vascular spaces.

The trabeculæ, or columns, of the hepatic cells consist sometimes of 1 to 3, more rarely of 4 to 5 rows of cells; they have a diameter of 0·01‴ to 0·015‴ in the average, 0·006‴ to 0·02‴ in the extremes, and are, in general, cylindrical or prismatic, although by no means regularly so; but sometimes of one form, sometimes of another, with arched, and even in some places depressed surfaces, and rounded or sharp borders. The meshes of the hepatic cell-network correspond to the diameters of the capillaries and the larger adjoining vessels of the hepatic islets, by which, during life, they are completely filled, as will be noticed more fully below.

According to the above, the secerning parenchyma of the liver contains throughout no *canals* which could be designated as finest or secreting biliary canals, as has been assumed by many authors (*Henle, Gerlach, Hyrtl, N. Guillot, Lereboullet*), but consist of solid networks of the hepatic cell-columns, which view was first distinctly asserted by me in 1852, and also estimated physiologically, after *Handfield Jones* had already described the hepatic lobules as being composed of solid rows of cells (see my *Micr. Anat.* II. 2).

The only question that can arise is, whether the columns of hepatic cells are surrounded by a delicate membrane, or whether they are free and directly applied to the capillary network. The former view has been advocated by many observers, especially by *Krukenberg, Schröder van der Kolk, Retzius, Theile, Backer*, and *Leidy*; but none of these has been able to demonstrate the existence of such a membrane beyond all doubt. Even *L. Beale*, to whom we are indebted for a most elaborate paper on the liver, and who has brought forward many facts in favour of the existence of delicate tubes of basement membrane, in which the liver-cells lie, is obliged to confess, that in many cases this membrane cannot be demonstrated. *Beale* says (On some Points in the Anatomy of the Liver, p. 44), 'The circumstances above enumerated impress me with the idea, that the liver is orginally composed of two distinct networks, which intimately interdigitate with or fit into each other—one containing the secreting cells, the other the blood. As development advances, the walls of these two sets of tubes gradually become incorporated, except in those situations where the capillary network is less dense, or where the meshes of the cell-containing network are more widely separated from each other, in which cases a distinct limitary membrane to the tubes containing the liver-cells can be demonstrated in the adult.' Further on he remarks:—'Under some circumstances, then, it is demonstrable that the basement membrane of the cell-containing network is distinct from the walls of the capillaries; but in the greater part of the lobule, where the two membranes come into close contact, they are incorporated, so that really the majority of the liver-cells, except where they are in contact with each other, are surrounded with blood, from which they are only separated by a thin layer of delicate structureless membrane.'

From this quotation, it may be seen that *Beale* agrees with me in one great point, viz., that the membranes around the network of liver-cells cannot be demonstrated in the interior of the lobule; on the other hand, the excellent observations of the able Professor of King's College have convinced me that such membranes really exist in the exterior parts of the lobules, at the points of communication between the smallest biliary ducts and the network of the secreting cells. But I cannot agree in the opinion which he expresses, that the liver-cells do not exactly fill the delicate tubes in which they lie, and that the bile passes along the tubes in the slight interstices between the cells and the basement membrane. According to my view, the spaces which are seen in an injected liver are not natural; and there can be no doubt that the bile is transmitted from cell to cell till it arrives to the smallest real *ducts*, whose communications with the network of cells will be described in the following paragraph.

Such a conduction through closed cells is, as vegetable physiology sufficiently shows, not impossible, only it will not, of course, take place so rapidly as in places where true canals subserve this purpose. Since the bile, as the more recent observations show more and more distinctly, is not merely secreted from the blood, but really formed in the liver, and, at the same time, is the most complex of the secretions, it may be supposed, that the peculiar arrangement of the secerning parenchyma in the liver has a very intimate relation with the above circumstances. In fact, the blood-plasma, when it has to pass through many cells, and suffer their metabolical influences, must undergo entirely different changes before it arrives at the excretory canals, than when it is separated from the canals of the glands only by a simple layer of cells and one or two structureless coats. The necessary slowness of the process in these circumstances, is compensated by the elaboration of the secretion and the size of the organ.

If nitric acid be added to the hepatic cells, they become, as *Backer* also mentions, greenish-yellow coloured. Sugar and sulphuric acid render them red. Water produces in the cells an abundant precipitate of dark granules, which generally dissolve readily and completely in acetic acid, so that the cells become more or less pale, as is also the case when only the acid is added. When the liver is boiled, the parenchyma becomes hard, and the cells appear contracted and granular. Diluted caustic alkalies quickly attack and dissolve the hepatic cells of animals; in man, the cells resist longer: still, they immediately swell up to double their previous size, become quite pale, and at length also disappear. Ether and alcohol, as also sulphuric and nitric acids, render the cells smaller and granular. The inference from these and the above-mentioned facts is, that the hepatic cells contain a considerable quantity of nitrogenous substances, bile-colouring matter, fat, and perhaps, also, the acids of the bile. The sugar, which more recent investigations have shown to be present in the liver, is, perhaps, to be considered as being formed in the parenchyma, in the cells accordingly, and not merely in the blood. The liver-cells of young mammalians are, according to the observations of *Gluge* and myself, very often found full of fat, so that the livers of such animals have the greatest resemblance with fatty livers.

§ 161. *Efferent Biliary Passages.*—The *hepatic duct*, with its branches, accompanies the portal vein and hepatic artery, so that a branch of the portal vein has always, on one side, a much narrower gall-duct, and on the other, an artery which is likewise narrow, and is surrounded along with them by an envelope of connective tissue, the *capsula Glissonii*, as it is termed. In man, the hepatic ducts ramify in an arborescent manner with the portal vein; they can be exposed with the knife for a considerable extent inwards, and can be traced with the microscope, in fresh and injected livers, as far as the lobules. Before they pass to the lobules, the hepatic ducts unite here and there by smaller branches; but the anastomoses of the small interlobular branches, coming from opposite points, are very rare (*Beale*). From these interlobular ducts finer branches are given off to the lobules, and, in the human subject according to *Beale*, are connected together so as to form a lax network of ducts, which is directly continuous with the lobular network of liver-cells, as represented in fig. 150, after *L. Beale*, who first

Fig. 150.

Termination of a small interlobular duct in the pig's liver, and communication of its smallest branches with the network of tubes containing liver-cells.

succeeded in showing the manner in which these two structures unite. The smallest ducts are lined with a single layer of very delicate, flattened epithelial cells, and not wider than $\frac{1}{3000}$th of an inch; therefore, they contrast remarkably with the tubes of the secreting network, whose breadth is about $\frac{1}{1000}$th of an inch and whose cells are nearly of the same size.

All the hepatic ducts down to canals of 0·1‴ in diameter, consist of a thick fibrous coat, of dense areolar tissue, with numerous nuclei and elastic fibrils, and of a cylindrical epithelium 0·01‴ in thickness, which, in ducts below 0·04‴ to 0·05‴ in diameter, is gradually converted into a pavement epithelium. The ductus choledochus and cystic duct are similarly constructed, only their walls are thinner, and are distinctly sub-divided into a mucous membrane and a fibrous layer, which latter also contains a few *muscular fibre-cells*, though, upon the whole, so sparingly, that these ducts cannot be said to possess a special muscular coat.

The gall-bladder possesses a delicate *muscular coat*, between the peritoneal covering and the abundant submucous tissue, whose fibre-cells, 0·03‴ to 0·04‴ long, run chiefly in the longitudinal and transverse direction, and have only indistinct nuclei. The mucous membrane is characterised by numerous larger and smaller reticulated folds, in which there exists a capillary network entirely similar to that of the broad intestinal villi. It is covered with a cylindrical epithelium, whose separate cells, like the coats of the bladder in general, are often tinged with bile, and do not always present distinct nuclei.

The biliary ducts contain in their walls a number of small, racemose, yellowish mucous glands, gall-duct-glands, as they are termed, whose glandular vesicles, 0·016‴ to 0·024‴ in size, do not essentially deviate from those of other small racemose glands. In the *ductus hepaticus*, *choledochus*, and the lower part of the *cysticus*, the glands are very numerous in, and in part external to, the fibrous coat, of $\frac{1}{4}$‴ to 1‴ and more in size, and open singly or several together, by mouths of 0·1‴ to 0·14‴ in diameter, which are visible to the naked eye, and give the mucous membrane of these canals a reticulate appearance. At the commencement of the cystic-duct the glands are rare, and are, in any case, not constant in the gall-bladder, in which some believe they have seen them. On the other hand, glands are seen in the branches of the *ductus hepaticus* as far as those of $\frac{1}{3}$‴ in diameter, and open in part with two rows of minute openings, visible in these ducts.

We have still to notice here some peculiar ramifications of the bile-ducts, the *vasa aberrantia (E. H. Weber)*. They are met with—in the *ligamentum triangulare sinistrum*, in the membranous pons, which connects the Spigelian and right lobes behind the vena cava, then in the membranous pons which often covers the vena umbilicalis, in the large portal canals *(Beale)*, and at the border of the fossa of the gall-bladder—as canals, 0·006‴ to 0·027‴ wide, and consisting of a fibrous coat and small cells. In the *fossa transversa hepatis*, the right and left branch of the ductus hepaticus (and its smaller branches in this situation), give off, according to *E. H. Weber*, a number of finer twigs, which spread out in the connective tissue of the capsule of *Glisson* covering the fossa, and form a network, which thus connects the right and left hepatic duct. Many smaller branches of these gall-ducts terminate with short swollen extremities, $\frac{1}{25}$‴ to $\frac{1}{18}$‴ in diameter; and upon the walls of these ducts, in general, there exist a number of roundish projections, which, like the walls of the smallest bronchial ramifications, appear to be formed by flattened, coalesced vesicles having wide communications with the cavity of the canals. What *Weber* thus describes as *vasa aberrantia*, were subsequently described by *Theile* as glands of the biliary ducts. On the other hand, *L. Beale* has not only adopted *Weber's* opinion on these structures, but goes so far as to regard all the reputed mucous glands of the hepatic ducts as parts of the biliary canals.

The bile is normally quite fluid, and contains epithelial cells only as an accidental mixture from the larger gall-ducts. Liver-cells never occur in it, and are only *accidentally* and in few instances met with in the smaller ducts (*Wharton Jones, L. Beale*). Constituents which, though abnormal, are very frequent, are — fat-globules, colouring matter of the bile in the form of granules or granular masses, which, as in the hepatic cells, are separated in considerable quantities, in the bile itself, under certain circumstances. With these there are to be ranked, but of more rare occurrence, crystals of cholesterine, and especially the reddish needles of bilifulvin, which were very recently observed by *Virchow*. According to *Virchow*, the epithelial cells of the gall-bladder have the same structure as those of the small intestine, and are also often found filled with fat, which, as *Virchow* supposes, has been absorbed from the bile (VIRCH. *Arch.*, LXI.).

§ 162. *Vessels and Nerves of the Liver.*—The liver is altogether singular in respect of its blood-vessels, inasmuch as, besides an artery and a returning vein, it possesses an afferent vein, the portal vein. Whilst the latter vessel supplies, properly speaking, the secreting parenchyma, and is by the capillary network there situated directly continued into the hepatic veins, the artery is destined more for the nourishment of the walls of the bile-ducts, the portal vein itself, the capsule of *Glisson*, and the serous investment of the liver, and takes only a subordinate share in the formation of the capillary network of the hepatic islets. The ramifications of the *portal vein*, and of some small veins of the gall-bladder, and of the stomach (see WEBER, *Ann. Acad.*, II., 1845), which pass into the liver separately, generally take place dichotomously; still, besides the main branches into which they divide, a number of smaller vessels pass off at right angles, both from the largest and from the somewhat smaller branches. These vessels, passing off at right angles, betake themselves, often immediately, often after a very short course, to the hepatic islets, which bound the principal vascular canals; whilst the portal branches, all becoming more and more branched and attenuated, have to run, for a greater or less distance according to their diameter, through liver-parenchyma in the vascular canals, lined by the capsule of *Glisson*, before they proceed to the hepatic islets or lobules. Each of these receives from the one or the other order of portal branches at least 3, mostly 4 or 5 small vessels, $\frac{1}{120}'''$ to $\frac{1}{60}'''$ in diameter, which *Kiernan* calls *venæ interlobulares*; still, such a vein never supplies only one hepatic islet, but always two, or even three. Their ultimate twigs, *rami lobulares (Kiernan)*, penetrate, to the number of ten, fifteen, or twenty, and mostly at right angles, into the neighbouring lobules, and immediately break up into the capillary network, without, in man, being in direct connection with each other. Anastomoses of the portal branches are extremely seldom met with (*L. Beale*), their ramifications being connected only by the finest vascular network of the organ.

The *capillary network* of the hepatic islets completely fills up the interspaces of the hepatic cell-network, so that the secreting parenchyma of the liver consists only of two elements, the hepatic cells and the blood-capillaries. Just as the hepatic cell-network forms a connected whole throughout the liver, although it is divided into numerous minute patches by vessels which enter into, and gall-ducts, which issue from it regularly at stated distances; so also the capillary network of the blood-vessels, passes from one hepatic lobule to the other, although it presents interruptions at certain places. The width of the capillaries is generally somewhat less than that of the hepatic cell-network, but still proportionally considerable, being, in man, 0·004‴ to 0·0055‴, on an average, 0·002‴ to 0·01‴ in the extremes; and the wider vessels are situated especially in the neighbourhood of the entering and departing veins of the lobules, the narrowest in the middle between the two. The meshes of the network correspond, of course, to the form of the hepatic cell-network, and are, accordingly, more elongated in the interior parts of the lobules and more roundish towards the circumference, whilst their breadth equals that of the trabeculæ of the hepatic cells, and amounts to 0·006‴ to 0·02‴.

The hepatic veins essentially resemble the portal, in so far as they have no valves, ramify in an arborescent manner at acute angles, do not anastomose, and receive along with larger branches a number of small vessels. On the other hand, these veins lie apart from the other vessels, in special canals of the hepatic substance, and are firmly connected with it, so that, when cut through, they do not collapse, and are destitute, at least in the finer ramifications, of an outer covering of connective tissue, which is but very slightly developed even in the largest trunks. But the relations of the ultimate branches of the hepatic veins, which *Kiernan* calls *venæ intralobulares*, and *Krukenberg*, *venæ centrales*, is quite different from that which the *vena portæ* presents. These intralobular veins, 0·012‴ to 0·03‴ in diameter, in man, it is best to study first in some animal whose liver is divided into isolated lobules, as in the pig; from which, indeed, *Kiernan* has taken his figures, which are to some extent diagrammatical. If a small branch of a hepatic vein be opened in the animal mentioned, there are distinctly seen, through the walls of the vessel, polygonal areolæ, which represent the surfaces of the lobules directed towards, and bounding the vein.

A small vein, passing out of the middle of each of these surfaces, which *Kiernan* calls bases of the lobules, opens directly into the larger vessel, and, when traced upon the opposite side, leads to the interior of a lobule, where, arising from the capillary network it never passes further to a second or third lobule. Thus there comes out of every lobule always only one vein, which, on this account, may be called *vena intralobularis*. The vessels, into which these veins immediately open, are called by *Kiernan sub-lobulares*, because they run along the basal surfaces of the lobules. They are sometimes larger in the pig, up to 1‴ to 2‴ in diameter, and then lie in canals, surrounded by the basal surfaces of a certain number of lobules; sometimes they are finer or very fine, down to $\frac{1}{30}$‴, and then they run only between the lobules. The sub-lobular veins unite to form larger veins, which no longer directly receive *venæ intralobulares*; and, accordingly, are limited only in part, or not all, by the basal surfaces of the lobules, but by their lateral surfaces or apices (capsular surfaces, *Kiernan*). Such veins, when they are small, still receive sublobular veins from groups of lobules directly bounding them; or, lastly, only larger veins, which present the same conditions as they themselves.

Fig. 151.

Section of a very successful injection of the hepatic veins of the rabbit; magnified 35 times. One, *vena intralobularis*, is visible in its whole course, the other only at its roots. The capillaries of the lobules coalesce in part, as also, at one place, two venous radicles. From a preparation of *Harting*.

The relations of the *venæ intralobulares* are very simple. Every one of them penetrates in a straight direction into the axis of a hepatic islet or lobule, splits up, somewhere about the middle, into two or three main branches, which frequently once more divide. The capillaries open not only into the extremities of these veins, but also into their trunklets during their whole course; and, according to *Theile*, capillaries open even into the commencements of the sublobular veins. In all lobules or islets, whose capsular surfaces are directed either towards the surface of the liver, or towards a large vascular trunk, the intralobular vein extends nearly to their ends; whilst in others they remain more in the middle, so that they are everywhere distant about the half of the diameter of the lobules from the next interlobular veins of the venæ portæ.

The hepatic artery accompanies, for the most part, the portal vein and bile-ducts, lies together with the latter within the capsule of *Glisson*, and presents, in its main ramifications, exactly the same conditions as the portal vein. Its terminal distribution takes place upon the vessels and bile-ducts, as also on the capsule of *Glisson*, in the fibrous and serous covering of the liver, and in the hepatic lobules; and they are, accordingly, distinguished into *rami vasculares, capsulares*, and *lobulares*.

1. *Rami vasculares*.—During its ramification with the portal vein, the hepatic artery gives off, mostly at right angles, a number of small branches, which form a plexus in the Glissonian enveloping tissue, from which there arise, in part, lobular branches destined to the sides of the portal canals which do not adjoin the main branches of the artery, and, in part, numerous twigs for the *walls of the portal vein*, the *larger branches of the artery itself*, the *hepatic veins*, the *capsule of Glisson*, and the *bile-ducts*. This vascular expansion is especially well marked on the ducts, so that after a successful injection, they appear almost as red as the arteries. The *venæ vasculares* arise from a moderately wide capillary network present in all the above-mentioned parts and around the glands of the gall-ducts. As *Ferrein* discovered, and as *Kiernan* and later observers have confirmed, these veins open not into the hepatic veins, but into small branches of the portal vein, as they go off from larger, within the capsule of *Glisson*, and are, therefore, to be regarded as *inner or hepatic roots of the portal vein*. For this reason, the portal vein can, in part, be injected from the hepatic artery, and *vice versâ*; and the vascular network in question becomes filled from both sides on injecting the hepatic artery and portal vein; whilst, on the other hand, it is impossible to inject it directly from the hepatic veins.

2. *Rami capsulares*.—Excepting some branches running to the *fossa ductûs venosi, ligamentum teres* and *suspensorium*, before the entrance of the artery into the liver, all the arterial branches of the envelope of the liver are terminal twigs of certain arteries distributed in the

lobules, as in the pig; from which, indeed, *Kiernan* has taken his figures, which are to some extent diagrammatical. If a small branch of a hepatic vein be opened in the animal mentioned, there are distinctly seen, through the walls of the vessel, polygonal areolæ, which represent the surfaces of the lobules directed towards, and bounding the vein.

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organ, which make their appearance at various places of the surface between the lobules. These vessels, measuring in the adult $\frac{1}{30}'''$ to $\frac{1}{20}'''$ in diameter (*Theile*), in the child to $\frac{1}{5}'''$, divide, at their places of exit, and some even previously, in a stellate manner into from 3 to 5 subordinate branches, which run in a spirally twisted manner, anastomosing in various ways, and then cover the entire surface of the liver, as far as the large venous trunks (*venæ hepaticæ, vena portæ, cava inferior*), the fossæ and borders of the organ, with a beautiful arterial network. These arteries, finally, form a wide-meshed plexus of capillaries, and lead, at least in many places, — whether everywhere, I know not, — into veins which run back alongside the arterial vessels, penetrate into the substance of the liver, and open into branches of the portal vein. Accordingly, there would also appear to exist *venæ advehentes capsulares*, or roots of the portal vein, derived from the source mentioned. The arteries and veins of the envelope of the liver are connected at their termination, on the one hand, with branches of the *vasa mammaria interna, phrenica, cystica,* with the *supra-renalia,* and *renalia dextra* (*Theile*); and, on the other, with those of the capsule of *Glisson,* vena cava and hepatic veins, in the fossæ of the liver.

3. *Rami lobulares.*—With every interlobular vein there runs a branch of the hepatic artery, of at most $\frac{1}{130}'''$ in diameter (*Theile*), which divides between the lobules (in the pig, in the capsules of the lobules), into fine anastomosing ramules, and is directly connected with the peripheral part of the capillary network of the hepatic lobules or islets, which, as above explained, is formed by the portal vein. Accordingly, arterial blood, though in small quantity, is also concerned in the preparation of the bile, and, in this circumstance, the hepatic artery is different from the bronchial arteries, whose blood is in part conveyed away by special veins.

The *lymphatics* of the liver are very numerous, and are divisible into *superficial networks*, situated beneath the serous covering, and deep vessels, which accompany the portal vein, and, in animals, at least, the hepatic veins also. Both systems of vessels are connected with each other, and lead, partly through the diaphragm, into the thoracic cavity, partly to small lymphatic glands in the transverse fissure, and to the visceral plexuses. The lymphatics of the gall-bladder also are extremely numerous.

The *nerves* of the liver are relatively very numerous; they arise from the sympathetic, and, in part, from the vagus, and are especially distributed with the hepatic artery, which they surround with non-ganglionated networks. In addition to numerous fine tubes and fibres of *Remak*, they always contain some thick fibres. They may be traced: 1. on the *gall-bladder* and the *large bile-ducts*; 2. in the *capsule of Glisson*, as far as the interlobular arteries, where the finest branches, of 0·008‴ to 0·012‴ in diameter, possess only nucleated fibres; 3. to the *hepatic veins*; lastly, 4. into the coats of the liver.

In the transverse fissure of the human liver, in the large portal canals, and in the gall-bladder of the human subject, a very peculiar arrangement of the vessels occurs. Both arteries and veins form a *network*, and each branch of the artery is accompanied with *two* branches of the vein, one on either side of it (*E. H. Weber*, *L. Beale*).

§ 163. The development of the liver may, according to the most recent observations of *Bischoff* and *Remak*, be best understood in the following manner:—The primitive rudiment of the liver, appearing, as is well known, very early (in the chick, at the fifty-fifth and fifty-eighth hour; in mammalia, after the Wolffian bodies and the allantois), consists of two collections of cells, an outer, which has arisen from the fibrous coat of the intestine, and an inner epithelial, which forms at first a simple, and then a bifurcated tube. From the epithelial layer, which, like the intestine, at first consists of round cells, perhaps in several strata, there are formed, by the multiplication of cells, solid outgrowths into the outer layer, the *hepatic cylinders* of *Remak*, which, in their further growth, *ramify* and *anastomose*; whilst, at the same time, the cells of the outer layer, enclosed in the meshes of this network, likewise multiply, and become successively converted into vessels, nerves, connective tissue, etc. It is difficult, however, to say in what manner, out of this peculiar reticulated parenchyma of cells and vascular rudiments, the subsequent conditions are evolved. The hepatic cell-networks and lobules of the fully developed liver are obviously produced by the further growth of the primitive hepatic cylinders, which, by the continued multiplication of cells, successively put forth new processes, and join again and again in a reticulate manner; so that the hepatic cell-network of the fully developed liver appears thus to be lineally derived from the primitive network. With respect to the *bile-ducts*, they certainly originate as secondary excavations of a part of the originally solid hepatic cylinders and of the larger inner cords, bordering upon the primitive protrusion of the epithelium (all of which consist of several rows of cells), which excavation advances from the common bile-duct to the branches. In this way of viewing the matter, there is only this difficulty, viz., that, according to *Remak*, all the hepatic cylinders, even the largest, form anastomoses; whilst, as is well known, the bile-ducts ramify without anastomosing with each other. Here we are forced to assume that the anastomoses of the originally largest hepatic cylinders do not, in the course of development, keep pace with the other parts, but are *absorbed*; an assumption supported by many analogous phenomena of fœtal development. There would appear, however, to be an exception to this in man (and in some animals, *L. Beale*); for it seems to me, that the above-mentioned anastomoses of the right and left hepatic duct in the *fossa hepatis*, as described by *E. H. Weber*, are satisfactorily explained by the observations of *Remak*, and are nothing else than the embryonic anastomoses of the rudiments of these canals, which have advanced to a certain, though not considerable degree of development. According to *Remak*, the gall-bladder in the chick is, at first, a solid outgrowth of one of the bile-ducts, which subsequently becomes hollow, and quickly enlarges. I observed the folds of its mucous membrane in a human fœtus of five months.

In the *investigation* of the liver it is best to commence with that of the pig, in which animal the distinct separation of the lobules very much facilitates the understanding of the relations of the secreting parenchyma to the vessels and ducts. The hepatic cells can be isolated in all animals with the greatest readiness, either singly, or in rows, or as fragments of the network; in order, on the other hand, to understand correctly their general arrangement, there is no better plan than to make fine sections of a fresh liver with the double knife, which are far superior to those made in the ordinary way with a razor, even when the liver has been previously hardened in alcohol, pyroligneous acid, chromic acid, etc. We do not, however, mean to say that the hepatic cell-networks cannot be seen by the latter mode of preparation, for they can be perceived even in opaque parts of the liver when viewed by reflected light, only that such method does not afford a perfect view of the structure. The finest bile-ducts are not easy to find, still, in sections which pass through several lobules, fragments of them, which are readily recognisable by their small polygonal cells, may be perceived, on careful examination, at the border of the lobules, almost in every preparation; and perhaps, after long-continued investigation, such a fragment may be seen in connection with the hepatic cell-network, though I have not, hitherto, been so successful as to observe this. The larger bile-ducts present no difficulties. Their glands are readily seen, partly with the naked eye, partly with a lens after the addition of caustic soda; and the Weberian anastomoses of the two hepatic ducts in the *fossa transversa*, may be discovered in good injections. The *vasa aberrantia*, in the *lig. triang. sinistrum*, and in other places, are perceptible without injection, after the addition of acetic acid or caustic soda. The nerves and lymphatics of the liver are also, up to a certain point, readily seen in man. The blood-vessels require good injections, and for this I recommend the livers of children, rather than of adults. In children, particularly, the ramifications of the hepatic artery copiously distributed in the serous covering, on the vessels and elsewhere, have a fine appearance. The capillary network of the lobules can be readily injected with fine size, and a series of excellent injections, by various masters of the art, is to be met with everywhere.

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VI. OF THE PANCREAS.

§ 164. The pancreas is a compound racemose gland, which agrees so very closely with the salivary glands, that a short description of its characters will suffice. As in all such glands, we may very plainly distinguish larger, smaller, and still smaller lobules. The ultimate lobules are composed of microscopical glandular vesicles of moderate size (0·02‴ to 0·04‴), and mostly roundish in form. Here, as elsewhere, these vesicles have a *membrana propria* and a pavement epithelium. The cells of this epithelium contain a substance precipitable by acetic acid, and again soluble in excess of the re-agent; this is probably identical with the protein substance of the pancreatic juice. The cells are frequently remarkable for a multitude of fat granules, so that the glandular vesicles appear quite dark, and as if completely filled with cells. The excretory ducts are, as usual, connected with the gland-vesicles, join together into larger canals, and ultimately form, by their union, the *ductus Wirsungianus*. They are whitish and rather thin-walled, they are composed solely of connective tissue with elastic fibrils, and they all possess an epithelium of small cylindrical cells, which scarcely exceed 0·006‴ to 0·008‴ in length, and 0·002‴ in breadth. In the walls of the *ductus Wirsungianus*, and its larger branches, are placed numerous small racemose glandules, 0·06‴ to 0·08‴ in diameter, with vesicles of 0·016‴ to 0·02‴, whose epithelial cells contain but little fat: these are nothing else than *mucous glands*, analogous to the glands of the bile-ducts. According to *Verneuil*, the canal from the head of the pancreas not only opens into the main duct, but has also a separate narrow aperture into the intestine; in its course this *D. pancr. azygos* (*Verneuil*) passes indifferently over or under the larger duct. See *Beau et Bonamy*, iv., pl. 34.

The pancreas possesses the ordinary connective tissue of glands, with a variable number of fat-cells, and in this the *vessels* and *nerves* of the gland branch out. The former present exactly the same conditions as in the parotid, only that the lymphatics appear to be more numerous; and with regard to the latter, it appears that they accompany the vessels only: they spring from the sympathetic, and contain fine fibres of medium thickness. The *secretion* of the pancreas is, normally, a clear fluid, any solid particles mixed in it not being an essential part, such as detached epithelium of the gland-vesicles and ducts.

The *development* of the pancreas commences with an outgrowth from the posterior wall of the duodenum, and advances onwards, as in the salivary glands, only that the gland-rudiment forms, at first, a more compact mass, and cannot, therefore, be so well observed in its individual parts.

The investigation of the pancreas presents no difficulties, except that the fat of the epithelial cells of the gland-vesicles disturbs their observation in man; and the pancreas of the lower mammalia (rabbit, or mouse), where there is much less fat, should, therefore, also be studied. The glandules upon the ducts are best seen after the addition of acetic acid.

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VII. OF THE SPLEEN.

§ 165. The spleen is one of the so-called vascular glands, and stands in a certain relation to the renovation of the blood, and probably, also, to the secretion of the bile. With reference to its structure, it consists of a *fibrous* and *serous envelope*, and of a soft *parenchyma*, which is principally composed of reticulated firm trabeculæ, the *splenic trabeculæ*, and of a red substance enclosed by them, the *splenic pulp*. In the latter, again, there are contained numerous peculiar whitish bodies, the *splenic corpuscles*; and through the whole interior there are distributed numerous *vessels* and a certain number of *nerves*.

§ 166. *Envelopes and Trabecular Tissue.*—The peritoneal envelope covers the entire surface of the spleen, with the exception of the hilus, whence it is continued to the fundus of the stomach, over the splenic vessels and nerves, and has the name of the gastro-splenic ligament. At the upper end, also, the peritoneum is reflected as the *lig. phrenico-lienale*, or suspensory ligament. In man, but not in ruminant animals, the serous coat is so firmly connected with the fibrous envelope, that it can only be pulled off from the organ in shreds.

The fibrous envelope (*tunica fibrosa, albuginea, seu propria*) forms a complete investment to the spleen. Although very firm, this coat is rather thin and transparent; at the hilus, it is continued into the interior, and conducts the splenic vessels as far as their finer ramifications: here it forms special sheaths, *vaginæ vasorum*, similar to the capsule of *Glisson* in the liver. In man, this exterior extension consists of ordinary connective tissue; but in certain animals, smooth muscular fibres, in considerable number, have been demonstrated in my researches. I have seen these fibres in the dog, pig, ass, and cat, but not in the rabbit, horse, ox, hedgehog, porpoise, or bat.

The trabeculæ of the spleen are white glistening fibres, flattened or cylindrical, of an average diameter of $\frac{1}{10}'''$ to $\frac{1}{3}'''$, which arise in great numbers from the inner surface of the fibrous tunic, and also, though more sparingly, from the outer surface of the sheaths of the vessels. These become united with similar trabeculæ in the interior of the spleen, and form a network which extends through

Fig. 152.

Transverse section through the middle of the spleen of the ox, washed out in order to show the trabeculæ and their arrangement. Natural size.

the whole organ. The spaces enclosed in the meshes of this network are all connected with each other, and contain the red splenic substance and the corpuscles. Although no one is exactly the same as another, these spaces do possess a certain resemblance to each other in form and size. The older anatomists regarded them as regular cavities lined by a membrane, analogous to the venous areolæ of the *corpora cavernosa penis*. It is true that the interstices of the splenic structure closely resemble these areolæ in the arrangement of the trabeculæ round them, but it is certain that they have no limitary membrane of any kind; this is best proved on a section of the spleen after the pulp has been removed by washing. Such a preparation also furnishes us with the best means of studying the relations and connection of the trabeculæ. They are seen to be altogether irregular in their mode of connection with each other, and present no similarity to the ramifications of vessels. They are very variable in thickness. At the spot where four or five, or more of these trabeculæ become united, we usually meet with a flattened cylindrical nodule, resembling a ganglion on a nerve; these are found more frequently towards the outer surface of the organ than in the inner parts and at the hilus, where the large vessels furnish a sufficient support to the parenchyma, and such a provision for the firmer union of the trabeculæ is, therefore, less required.

The *structure* of the trabeculæ of the human spleen corresponds entirely with that of the fibrous envelope, and both consist of connective tissue, running in a longitudinal direction, with fine elastic fibres. In animals, on the other hand, smooth muscular fibres, having a longitudinal direction, are met with in the trabeculæ. These were first exhibited by myself in 1846. In some animals (pig, dog, cat), they are found in all the trabeculæ; in others, as the ox, they exist only in the smaller ones. *Hlasek* and *Crisp* consider them only the muscular fibres in the walls of the vessels; but this is positively an error. Particulars of their distribution will be found in my *Micros. Anat.*, ii. p. 256.

§ 167. *Malpighian Corpuscles.*—The splenic corpuscles, Malpighian corpuscles, or splenic vesicles, are white roundish corpuscles, which are imbedded in the red splenic substance, and are connected with the smallest arteries. They are invariably recognised easily in the fresh bodies of healthy subjects, but rarely, or not all, in such as have died from disease, or after long abstinence. This is the explanation of the circumstance that *Von Hessling* found the corpuscles 116 times only in 960 bodies examined by him, and that they were present with less and less frequency as the subject was older. In children under two years, they were found in every second instance; from two to ten years, in every third case only. Children dying between ten and fourteen, presented the corpuscles but once in sixteen times; while persons above fourteen showed them only half as often as this. In the bodies of such, also, as have died suddenly, from accident or suicide, and in executed criminals (of which latter I have examined four cases), they are, perhaps, never absent; and, in such cases, they are just as numerous and distinct as in the lower mammalia.

Fig. 153.

A part of a small artery, with a branch studded with Malpighian corpuscles. From the dog. Magnified 10 times.

In man and in animals, the *size* of the splenic corpuscles is subject to certain variations, and has, hitherto, been mostly overestimated, because they had not been properly isolated. They measure from $\frac{1}{10}'''$ to $\frac{1}{3}'''$, the average being $\frac{1}{6}'''$. It is very possible that their size varies according to the condition of the chylopoietic organs, the corpuscles being larger after the absorption of nourishment than at other times. In animals, however, I can affirm with *Ecker*, that they are frequently strongly marked during fasting; and no data exist to determine this point in man.

The Malpighian corpuscles are imbedded in the red splenic substance, and can scarcely be completely separated from it. They are always attached to an arterial twig, and are either sessile on the side or at the bifurcation of a vessel, or attached by a stalk, which is itself a small artery. Their number is very considerable, and arterial twigs, of 0·02''' to 0·04''' in diameter, support five to ten corpuscles. These present, when freed from the pulp, a beautifully clustered appearance (fig. 153). It is estimated that every cubic line, or line and a half, contains one of these corpuscles; and this appears to me to be rather below than above the truth.

With regard to their *intimate structure*, every Malpighian corpuscle consists of matters contained within a special envelope, and is, accordingly, a *vesicle*. The membrane is colourless, transparent, 0·001‴ to 0·002‴ thick, and is everywhere bounded by a double contour, in which there occasionally appear concentric lines. It is intimately connected with the sheath of the vessels, and so far resembles this in structure, that they both contain a homogeneous connective tissue and elastic fibres. On the other hand, the smooth muscular fibres, which, in many animals, are found running longitudinally in the sheaths of the vessels, are completely absent from the membrane of the Malpighian body. These corpuscles contain no epithelium in their interior, but are stuffed with a viscid coherent substance, of a greyish-white colour. This is composed of a multitude of cells in a small quantity of fluid. The fluid is clear and neutral; it is coagulable by heat, and is, therefore, albuminous. The cells are pale, roundish, vary in size from 0·003‴ to 0·006‴, and most of them have but one nucleus; these cells are rendered granular by water. There is also a variable number of free nuclei, which, however, were wanting in my most recent experiments, made with great care; all free nuclei having been derived from the rupture of the cells. The cells frequently contain separate fat granules, and they furnish very distinct proof that a continual process of cell-formation is going on in the Malpighian bodies. Besides the cells, blood-corpuscles are also found in particular instances in these bodies, sometimes altered, sometimes unaltered, free or enclosed in cells. Fine *blood-vessels* are also found, as in the follicles of Peyer's glands (see above). This observation was first made by myself on the spleen of a cat in the year 1852, and has since been confirmed by *Sanders* in the pig, by *Gerlach* in the sheep, by *Leydig* in the coluber, and by myself in man.

Fig. 154.

A Malpighian corpuscle, from the spleen of the ox; magnified 150 times. *a*. Wall of the corpuscle. *b*. Contents. *e*. Wall of the artery, upon which it is seated. *d*. Sheath of the same.

The Malpighian corpuscles are completely closed sacs, and are related anatomically to the follicles of the Peyerian and solitary glands, already described, and also to those of the tonsils and lymphatic glands. On this account, they may, for the present, be designated *glandular follicles*. The supposition of many authors, old and recent, that these bodies are connected with lymphatic vessels, although probable, has not, hitherto, been established. *Gerlach* formerly believed that they were the widened commencements of the lymphatics; but since I discovered the blood-vessels in their interior, he has given up this view, and explains the corpuscles as being of the nature of lymphatic glands. Such interpretations would have greater claims to be received, if the relations of the corpuscles to the lymphatics were demonstrated; but this, I must still affirm, has not hitherto been done with precision. Even *Gerlach's* own injections, and his most recent description of lymphatic vessels given off from the corpuscles (*Handb.*, 2nd edit., p. 244), do not appear conclusive, any more than the earlier enquiries of *Evans, Schaffner*, and others. I myself am also disposed to class the Malpighian corpuscles with the lymphatic glands; but, it must be owned, that a complete identification of the two is impossible, for the Malpighian corpuscles never have lymphatic vessels leading to them. If, however, such vessels should hereafter be shown to exist in their interior, or to proceed from their surface, I should then regard the Malpighian bodies as a peculiar kind of *simple terminal lymphatic glands*, in which the colourless blood corpuscles are formed, in the same manner as in the complex glands in the course of the lymphatic vessels.—It is the opinion of *Leydig*, from researches on the lower animals, that the blood-vessels of the spleen are surrounded by lymphatics, and that the Malpighian bodies are only expansions of these. This view has assuredly no application in higher animals, for in them the corpuscles are closely fitted to the arteries that carry them, and there is no trace of any enveloping lymphatic canal.

Malpighian bodies are found in all mammalia and birds, wherever they have been sought. They are less constant in the class of reptiles, true Malpighian bodies never being found in the naked amphibia. In fishes, I have pointed out certain vesicles which *Leydig* considers as the representatives of Malpighian bodies, but which generally contain blood-globules only, and rarely cells. The Plagiostomous order alone have true undeniable Malpighian bodies. Hence *J. Müller's* opinion is not confirmed, that Malpighian corpuscles exist in all vertebrate animals; a point not without its importance, when we attempt to estimate their physiological significance.—In some of the lower mammalia, the Malpighian bodies contain, though not uniformly, disintegrated blood-corpuscles of the same form as will be presently described in the spleen-pulp.

§ 168. *The Red Splenic Substance, Splenic Pulp, or Parenchyma* (*substantia rubra, pulposa, parenchyma lienis*) is a soft reddish substance, which fills up all the interspaces between the larger trabeculæ and vessels, and, on account of its softness, may be readily removed from a section of the spleen. It consists of three elements, viz., of the *most delicate blood-vessels of the spleen, microscopical fibres and trabeculæ,* and *peculiar parenchyma-cells.* With these elements in man and animals, *blood,* in various stages of metamorphosis, is always found conjoined, so that it may almost be regarded as a normal constituent of the pulp. According to the quantity of this blood, and the degree of fulness of the blood-vessels, the pulp appears of a clearer or of a darker blood-red colour, although it is to be observed that the pulp also possesses red colouring matter of its own.

The fibres of the pulp are of two kinds. First, *microscopical trabeculæ,* quite analogous to and of the same structure as the larger ones which are seen by the naked eye, except that in many mammalia they contain more smooth muscular fibres, or are even composed of nothing else. Their diameter generally varies between 0·005‴ to 0·01‴, and their number and quantity are not uniform in different parts of the organ, nor in different animals. In man, I find them more scanty and broader than in the lower mammalia, and in structure completely resembling the large trabeculæ. The other fibres occurring in the pulp are obviously *terminations of the sheaths of the vessels.* They are met with in very large numbers, and especially appear in the form of delicate membranes, indistinctly fibrous in texture, without elastic tissue; they appear to unite the capillaries, and are, perhaps, also connected with the finest trabeculæ.

The *cells* of the splenic pulp, or parenchyma-cells of the spleen, are, for the most part, round cells with single nuclei, 0·003‴ to 0·005‴ in diameter, and so similar to those of the Malpighian corpuscle, that a detailed description is not needed. *Free nuclei* are likewise found intermingled with them, in larger numbers than in the Malpighian corpuscles; here, again, a more careful examination shows that the free nuclei occur accidentally only, perfect cells alone being the essential constituents of the pulp. Besides the foregoing, some other elements are noticed:—first, clear round homogeneous bodies, somewhat larger than blood-corpuscles, which appear to be smooth nuclei enclosed tightly by a thin envelope; secondly, large cells, measuring up to 0·01‴ in diameter, quite pale, with one or two nuclei; and, thirdly, there are found cells which contain dark, fat-like granules, without colour, and these I have named the 'colourless granular cells' of the spleen. These two last elements are found also, but in smaller numbers, in the Malpighian corpuscles. The various cells of the parenchyma are united by a small quantity of reddish-yellow fluid, and their quantity is so considerable as to form, probably, one-half of the entire red substance of the spleen. They are not aggregated into large collections, but form small irregular heaps of different sizes, occupying the interspaces between the trabeculæ, the vessels, and the Malpighian corpuscles. The arrangement may be most correctly understood, if we consider each segment of the red substance enclosed between the larger trabeculæ as representing a spleen in miniature. In fact, the microscopical trabeculæ, the terminations of the sheaths of the vessels, and the finest vessels, present the same arrangement as the corresponding larger structures visible to the naked eye; and the microscopical collections of pulp-cells may, in the same manner, be said to correspond with those larger segments of the parenchyma, which, to the unaided sight, appear homogeneous. Nowhere is there any special investment found to surround the parenchyma-cells, but they lie directly in contact with the sheaths of the vessels, the trabeculæ, and the envelopes of the Malpighian corpuscles.

The red pulp of man and of animals presents, at different times, a different colour, or, rather, a different behaviour of the contained blood-corpuscles, for on this condition especially depend the variations in colour. In one kind of animal it will present at one time a paler and greyish-red colour, while at another time it will be found brown or blackish-red. In the latter case, there are found a number of altered blood-corpuscles, of which we shall further have to speak; in the former case, on the other hand, it can be readily demonstrated, by microscopical examination, that the red colour is derived from unaltered blood-discs, which can also be readily pressed out of the tissue of the spleen, and, on the addition of water, soon give off all their colouring matter. In other animals, however, the spleen has always a pretty steady colour, which is generally dark; but in these, also, the blood-corpuscles are sometimes found unaltered, at other times, many of them are seen to be undergoing metamorphoses of various kinds. Now these metamorphoses are very striking and peculiar, and, in all animals, essentially depend upon the following changes: 1. The blood-globules, becoming smaller and darker, collect together in roundish heaps, the elliptical blood-corpuscles of the lower vertebrata becoming roundish. These heaps either remain in this condition, or go on to form cells. These cells result from the adhesion of the corpuscles by a sort of plasma, followed by the development of a nucleus in the interior of the heap, and of an outer envelope around it. The cells thus produced are spherical, from 0·005‴ to 0·015‴ in diameter, *with one to twenty blood-corpuscles in their interior*. 2. The next step is, that these collections and cells metamorphose themselves into *pigment collections* and *pigment-granule cells*. The blood-corpuscles become smaller and smaller, assuming a golden yellow, brown, or black colour, and become pigment granules either directly or after disintegration. The pigment-granule cells then undergo further change, the contained granules becoming paler and paler, until all colour is lost. In many cases, the blood-corpuscles do not form collections and cells, although they go through the same change of colour and the same disintegration as the others.

The red pulp of new-born and young mammalians contains, according to my observations, some interesting elements, viz., large cells with many nuclei, and small yellowish nucleated cells. The latter are undoubtedly nothing else than blood-corpuscles in process of formation, whilst the larger cells are also found in the blood of the splenic vein and of the vessels of the liver.

The changes of the blood in the spleen, first indicated by *Ecker* and myself, have since been the subject of repeated examination. Some observers, as *Gerlach* and *Schaffner*, regard the process as a redintegration of the blood-corpuscles. Others have even denied the existence of blood-containing cells, and contend that red blood-cells disappear in the spleen and become changed into pigment granules. My statements are confirmed in almost every particular by the later researches of *Virchow*, who considers, however, that the blood-corpuscles enter into the cells that contain them, subsequently to the formation of the outer cell.

It is an important question, whether the alterations of the blood-corpuscles in the spleen are to be regarded as physiological or as pathological processes. On the one hand, weighty reasons may be urged for considering them as normal; reasons derived from their constancy in the animal series, from the occurrence of similar cells containing blood-discs in the general circulation of amphibia, and from the circumstance that, in the higher vertebrata, these changes are observed with the same constancy in no organ besides the spleen. On the other hand, there are many and still stronger reasons for believing that these changes in the blood-corpuscles are abnormal only. In the first place, my investigations among fishes show, that these metamorphoses are not confined to the spleen, but are met with in the liver, and in the peritoneum; in the fish's spleen the changes occur within the vesicles (described in the preceding section), which look like the false aneurisms of pathologists (see my *Micros. Anat.*, ii., 2, and TODD'S *Cyclop. of Anat.*, art. *Spleen*, fig. 533; also ECKER, *Icon. Phys.*, plate vi., figs. 15, 16). Then, again, certain animals, as the cat and sheep, rarely exhibit these changes of the blood-corpuscles in the spleen, and there appears no constant relation between them and the state of digestion. In the third place, we must remember that very similar phenomena are observed with some constancy in other places, where they are never supposed to be physiological, as in little effusions of blood in the lungs, bronchial glands and thyroid of man, and in the mesenteric glands of the pig and rabbit.

From these considerations, I was forced (as early as 1854) to abandon the view, that the changes of the blood-discs in the splenic pulp belonged to the series of physiological appearances; I conceived that such changes, to be normal, must occur in the interior of vessels, and in this opinion I find myself supported by the great majority of physiologists. I am still of opinion that a solution of blood-cells actually does go on within the spleen, and in this organ much more than in the liver. But I have conclusively given up the grounds on which I originally upheld the physiological nature of this change, for I can no longer regard the occurrence of decomposed blood-cells in the pulp as establishing such a view.

§ 169. *Vessels and Nerves.*—At their entrance into the spleen, the splenic artery is relatively very large, and, with the still larger vein, is immediately surrounded by the continuations of the fibrous coat, the *sheaths of the vessels.* In man, these sheaths completely invest the vessels and nerves, somewhat after the manner of the capsule of *Glisson.* The arteries and nerves may be very readily isolated, the veins are more firmly connected with this sheath near the hilus. Around the main branches of the vessels the thickness of the sheaths is the same as that of their fibrous coats; but the finer branches of the vessels have thinner and thinner envelopes, until, on the most delicate vessels, the sheaths become very fine membranes, and lose themselves in the pulp. The thickness of a sheath is always less than the wall of the vein to which it belongs. As has been above mentioned, a number of trabeculæ become attached to the sheaths of the vessels, and the trabeculæ, sheaths, and vessels together take part in the formation of the dense network in the interior of the organ.—In mammalian animals, as in the horse, ass, ox, pig, sheep, etc., the sheaths present a different arrangement, being absent altogether from the smaller veins, and being met with, on the larger ones, only upon the side nearest to the arteries and nerves. It is only the two main venous trunks at the hilus which possess complete sheaths, whilst, on the arteries, a perfect investment may be traced, even to their finest ramifications. The structure of the sheaths is quite that of the trabeculæ, except that where the latter contain *muscular fibres,* such fibres are not always found in the former. Thus they are absent in the sheaths of the ox-spleen, though perfectly distinct in those of the pig.

The main trunks of the splenic *artery*, after its entrance into the spleen, immediately divide into a large number of branches in an arborescent manner, the larger branches proceeding to the anterior, the smaller to the posterior border of the organ. There is no anastomosis between the main branches of this artery. When they have become attenuated to $\frac{1}{5}'''$ to $\frac{1}{10}'''$ in diameter, they separate from the veins, with which, hitherto, they have been covered in the sheaths, and become connected by fine twigs with the Malpighian corpuscles in the manner already described. These small arteries are frequently attached firmly to the surface of the corpuscles, but I have never seen them pass through them, as *J. Müller* formerly supposed. They enter the red splenic substance, and immediately break up into beautiful tufts of very small arteries, the so-called *penicilli* (fig. 155), which then partly enter into the Malpighian

Fig. 155.

An artery with its tufted termination, from the spleen of the pig; magnified 25 times. After an injection by *Gerlach*.

corpuscles (see above, § 167), partly break up independently into true capillaries, 0·003''' to 0·005''' in diameter. These capillaries join in a widish meshwork, which surrounds the Malpighian corpuscles, and extends throughout the entire parenchyma.

With regard to the *veins* of the spleen, I am anxious, in the first place, to deny the existence of venous spaces (*sinus venosi*), described by both older and more modern anatomists, in the human spleen. The larger veins, so long as they accompany the arteries, offer nothing for remark beyond their width. They all possess a membrane, which is readily demonstrable, at least upon the side nearest the arteries, and this gradually becomes attenuated, together with the sheaths of the vessels. Openings of small veins, the so-called *stigmata Malpighii*, are frequent in the sides of the lesser splenic veins, but are found in smaller number on the main branches. As they pass onward, after leaving the arteries, the veins present a somewhat different arrangement. Firstly, a large number of small veins pass off from them at all sides, and mostly at right angles, so that their walls in some places appear perforated, almost like a sieve. Secondly, their membranes completely coalesce with the sheaths, so that, at last, the two only constitute a very delicate wall; this wall, however, can be demonstrated with ease in the finest vessels which are capable of isolation. I do not find enlargements in any part of these veins; and, it is only to be observed, that they become attenuated more slowly than the arteries. As for their connection with the capillaries, it takes place, in a part of the vessels at least, just as in other organs, and is easily seen by injection of a recent human spleen, especially in that of a child. In rarer cases, this mode of connection may also be observed by the microscope, for I have sometimes found small veins, in connexion with the capillaries, in the interior of the Malpighian bodies (*Würz. Verh.*, iv., p. 58). I will not, however, affirm that all the arteries and veins are connected in a regular manner through capillaries; for, in truth, all the more recent observations point to a connexion in some way between the splenic pulp and the blood-vessels. We must still hesitate, however, to receive any such view as demonstrated before it is thoroughly established by facts.

Fig. 156.

Epithelial cells of the splenic vein of man. Magnified 350 times.

The *epithelium* of the splenic vessels, especially of the vein, is readily detached after death, and then appears in very large quantities, apparently free in the pulp. The cells are spindle-shaped bodies, at first suggesting a resemblance to those of plain muscular fibre; they have a nucleus, which is frequently placed on one side. The cells are frequently rolled up together, and enclosed within a cell-like vesicle, probably formed around them during death. It was these cells that *Führer* recently described as developing capillaries, making use of them in constructing certain strange hypotheses on the formation of blood in the spleen, but into these we cannot further enter here.

The human spleen possesses, relatively, very few *lymphatic vessels*. The *superficial* ones run sparsely between the two envelopes; they are, however, scarcely recognisable, except in perfectly healthy spleens and in the neighbourhood of the hilus. The *deep* lymphatics are likewise few in number and of small diameter; they are met with in the hilus, from whence they proceed along with the arteries, although they cannot be followed nearly so far as the latter. Both systems of lymphatics meet at the hilus, pass through some glands in this situation, and finally become united into one trunk, which opens into the thoracic duct opposite the eleventh or twelfth vertebra. In morbid spleens, there is generally not a trace of the superficial lymphatics to be seen.

The *nerves* of the spleen, consisting of numerous fine and some thick tubes, with a moderate number of 'fibres of *Remak*,' arise from the splenic plexus around the splenic artery by two or three trunks, and are continued upon the arteries into the interior of the organ, either singly or in pairs, which occasionally anastomose. In the sheep and ox, these splenic nerves are truly colossal, so that, when taken together, they equal the empty and contracted splenic arteries in thickness; their great size, however, is only to be attributed to the unusually large number of fibres of *Remak*. In animals, the nerves, which are entirely destitute of ganglia, may be followed by the knife for a considerable distance into the spleen, further than in man; and with the aid of the microscope, I have frequently seen them, even upon the arteries which support the Malpighian corpuscles. Of the termination of the nerves, I can only affirm that they cross into the pulp and can be seen on the *penicilli*. They ultimately become as fine as the finest capillaries, and no longer contain dark-bordered tubes; at last, according to *Ecker's* observations (*l.c.* p. 149, fig. 10), they appear to end in free extremities after bifurcation. In the calf, the nerves, upon arteries of one line in diameter, measure 0·024‴ to 0·028‴; upon *penicilli arteriarum*, 0·0048‴ to 0·0056‴; in the midst of the pulp, 0·003‴ to 0·004‴. In trunklets of 0·012‴ to 0·028‴ in diameter, I have observed a single dark-bordered nerve-fibre, whilst all the rest consisted of a striated nucleated tissue, and this tissue alone was present in the finer fibrils. It is impossible to regard this as of the nature of connective tissue; but it appears probable, rather, that this, as well as the grey fibres of the nerve-trunks, is of an embryonic character. Further investigation into the origin of these tissues can alone determine the point. In the trunks of the splenic nerves of the calf, before their entrance into the spleen, and in its interior, there are seen numerous bifurcations of the dark-bordered primitive nerve-tubes, both of the finer and of the coarser tubes. These I have not yet succeeded in observing in man.

With reference to the veins, many of the *mammalia* appear entirely to agree with man; others, on the other hand, as the horse, ox, sheep, pig, differ very considerably. In these animals, a separate venous coat and vascular sheaths are only found at the commencement of the largest venous trunks, whilst further inwards, they are only distinct on the side nearest the artery. In all smaller veins, which run independently (without arteries), there is no longer any trace of two envelopes to be found, and, indeed, these veins soon appear to be simply excavations in the splenic substance, for a meshwork of trabeculæ, with red spleen pulp in the meshes, may be seen on their walls. They have, however, a perfectly smooth and shining surface, which is due to a covering of spindle-shaped, pavement epithelial cells, 0·005''' to 0·01''' in diameter. This layer is only demonstrable by the microscope; it corresponds completely to that of the larger veins, only that in these animals it does not lie upon a special wall, but immediately upon the splenic substance; in other words, upon the trabeculæ and upon the delicate membranous tissue, bounding the pulp between them. Such being the arrangement of the elements, we are perfectly justified in speaking of *venous sinuses*, especially when we consider that these veins, with these very attenuated walls, possess an enormous width, and are perforated by innumerable veins, which discharge their contents into them. These smaller veins themselves can be followed with the scissors for some distance; but I have not succeeded in demonstrating how they are connected with the capillary network, although this network, arising from the ordinary *penicilli arteriarum*, is itself very distinct. In truth, I do not think it likely that the mode of connection between the capillaries and the veins will ever be successfully made out; for the finest veins are such delicate canals, that they break up under the slightest mechanical force, as when blown out or injected, and can no longer be seen by the microscope. On the other hand, we are often able to trace veins onwards, until they become so fine that it is impossible to speak of their beginning in dilated extremities. So that it would appear that a portion of the veins arises by capillaries of the ordinary width, while it is probable that other very small veins open into wide interstitial spaces, their walls of membrane and epithelium being continued in some way with the structureless film of the spaces. Small rows of rounder epithelium, frequently found in the detritus of the pulp, probably belong to these last-mentioned very small veins.

The *lymphatic* vessels are stated by all authors to be very numerous in *mammalian* animals. This is quite true for the *vasa superficialia*, which are found in large numbers in the subserous tissue, where they anastomose in various ways; they are well seen in the calf. On the other hand, as I find, the *vasa profundiora* are here scanty. Thus I have counted in the hilus of the calf's spleen *only four lymphatic* trunks, having an aggregate diameter of

0·17‴ only. The larger lymphatics, in most animals, accompany the arteries. How they commence is unknown; and I can only affirm, that the arteries which bear the Malpighian bodies and the ultimate tufts are no longer accompanied by any lymphatics recognisable by the microscope. The structure of the lymphatics of the spleen offers no peculiarity; they are provided with valves.

The arteries of the human spleen are very muscular, and this completely suffices to explain the well-established increase and decrease which takes place in the size of the organ five or six hours after taking nourishment. In animals, the muscular fibres of the envelope and of the trabeculæ may also take part in this phenomenon, and their existence here will also explain how it is that spleens of animals contract more energetically when galvanised than the human spleen; still, even in this latter, contractions do occur, as has recently been observed in *Würzburg* in an executed criminal (see *Würz. Verh.* v.).

Quite recently, *Hlasek* has brought forward very peculiar opinions on the structure of the spleen. According to this author, there exists *no independent red splenic substance*, but it lies wholly *in the interior of anastomosing venous spaces;* and these spaces, covered by a regular epithelium, traverse the whole spleen and constitute its chief substance. The other parts of the spleen, envelope, trabeculæ, capillaries, nerves, splenic corpuscles, and lymphatic vessels, lie external to these cavernous veins, and contribute to the formation of their walls. How the capillaries are related to these venous spaces *Hlasek* does not state, but, in the opposite direction, he believes that the larger veins arise from the spaces by means of roots. Now, I hold this view of the structure of the spleen to be wholly incorrect, although it explains so plausibly the relation of the pulp to the formation of blood-corpuscles, and will be held to furnish a ready explanation of leucæmia in tumours of the spleen. Nothing is easier than to show that the cells of the pulp do not lie in spaces lined by epithelium, for they are everywhere directly in contact with the trabeculæ and Malpighian corpuscles — with the arteries, veins, and capillaries — with the nerves and sheaths, and on these parts there is assuredly no epithelial covering. From this it results, that the chief substance of the spleen certainly does not lie within blood-vessels; *Hlasek*, indeed, would explain the pulp as simply blood very rich in cells, ignoring the fact, that the splenic pulp has a strongly acid reaction, while the blood in the splenic vessels is alkaline as usual. Without asserting, therefore, that the mode of connexion between the capillaries and veins is positively made out, and without being prepared to state the exact relations of the cavernous venous spaces of ruminants (the existence of which in these animals and in the horse I admit), I am perfectly convinced that the account of the vessels given by *Hlasek* is incorrect.

Virchow and myself have recently established the fact, that elements of the splenic pulp (cells containing blood-globules, pigment-cells, simple pulp-cells, and pulp-cells with several nuclei) do pass into the blood-vessels, and, conversely, that normal blood-cells, as well as others in process of destruction, constantly occur in the pulp. There is, therefore, no room for doubt that the spaces which contain the splenic pulp stand in some normal relation with the blood-vessels; and the question then remains, which of the two theories we are to adopt: 1. the view expressed by me in a previous section, that *a part of the arteries and veins are connected in the usual manner through capil-*

laries, while in another part the union occurs only through the pulp-spaces; or 2. the hypothesis that *the capillaries have generally no direct connexion with the veins, but pass freely into the pulp;* so that the splenic blood travels without definite course through the pulp, just as by the latest observations, the chyle travels through the alveoli of the lymphatic glands. From the absence of conclusive evidence as to the facts, the choice between these two hypotheses is difficult; either of them is as available for the physiologist and pathologist as the statements of *Hlasek.* In fine, I would maintain the opinion I have already expressed as to the connexions of the vessels, for two chief reasons: first, that in man the capillaries may be actually traced into veins (in the Malpighian bodies, at all events); and secondly, that on no other hypothesis can we understand the different reaction of the splenic pulp from that of the blood in the vessels.

This, then, being our conception of the circulation in the spleen, we are certainly reminded somewhat of the corpora cavernosa in the larger mammalia, in which a part of the arteries and veins are connected by means of great venous spaces, while in the thick trabeculæ capillaries are met with in the ordinary manner. Suppose these spaces to be filled with a special parenchyma of cells, with capillaries running through it, and the structure would present a considerable similarity to that of the spleen. In any case, however, the pulp must not be regarded as merely a slowly moving blood rich in cells, but as a more stable element, which, while it gives and takes materials from the blood, still serves other purposes, as is indicated by the peculiar chemical properties of the splenic juice and by its acid reaction.

In the great obscurity which still surrounds the relation of the spleen pulp to the blood-vessels, we may be allowed to give consideration to statements which do not at first recommend themselves by being very intelligible. Such are the views of *Sasse*, *Billroth*, and *Gray*. According to *Sasse*, the pulp-cells are contained in tubes formed of homogeneous membrane with nuclei; and, by the rupture of these tubes, the cells become free and metamorphosed. *Billroth* states the parenchyma of the spleen to be a fine hollow network made up of cells, into which the arteries finally open, and from whence the veins spring; he comes to no conclusion about the formation of the red blood-discs, though he thinks the process goes on in the cells of his network. *Gray*, lastly, gives three ways in which the veins commence: 1. in direct prolongation from the capillaries, the most usual way; 2. from intercellular spaces in the pulp; and 3. by forming an imperfect envelope around the Malpighian bodies. Through the vagueness of the two latter statements, this author fails to afford a direct addition to our knowledge of the relations of the vessels.

§ 170. *Physiological Remarks.*—The spleen begins its *development* in the fœtus at the end of the second month, in a fold of peritoneum at the fundus of the stomach; it originates from a blastema, which has no connexion with the stomach, liver, or pancreas. At first it is a whitish body, often slightly marked into lobes, and assumes a red colour, from the development of blood and vessels within it. The roundish cells, which at first compose the whole spleen, develop themselves in the third month, partly into vessels and fibres, while a part remains as the cells of the parenchyma. The Malpighian bodies are of later growth, but they are seen, without exception, at the end of the fœtal period, although considerably smaller then than at a subsequent time. I do not know for certain how they originate, but I believe them to be produced from little masses of cells, the outermost of which develop into the fibrous envelope; while those of the interior remain partly in their original condition, partly are metamorphosed into blood-vessels.

This is not the proper place to discuss at length the *functions* of the spleen, for which I refer the reader to my *Micros. Anat.*, ii. 2, p. 282. Here I shall content myself by observing, that the most recent observations (*Würzb. Trans.*, vii.) tend to show that the spleen is essentially an organ in which colourless and also coloured blood-corpuscles are developed, which, after having been taken up by the veins of the organ, are in this manner mixed in the blood.

The *investigation of the spleen* presents, as far as certain conditions are concerned, no difficulties; the pulp, trabeculæ, envelope, and Malpighian corpuscles are found without any preparation. The Malpighian bodies are best examined first in the pig and ox, for in these animals the envelope and contents can be readily isolated, and the connexion with the vessels may also be seen. In order to see cells containing blood-corpuscles, the addition of water must be avoided. The muscular fibres may be very distinctly seen in the finer trabeculæ of the ox, pig, and dog, especially after maceration in nitric acid of 20 per cent. Injections of the arteries and capillaries can be readily made, the veins being difficult to inject; in the lower animals, even more difficult than in man. The nerves are readily found upon the arteries; the lymphatics are to be studied in the ox. In the examination of the pulp *Billroth* uses *liq. ferri sesquichl.*, and in man, chromic acid and glycerine.

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OF THE ORGANS OF RESPIRATION.

§ 171. In the respiratory organs are usually enumerated the *larynx*, *trachea*, and *lungs*. In this connexion, however, it will be proper to describe also the *thyroid* and the *thymus glands*, two organs which, at their origin, are related to the 'branchial arches' of the embryo, and which retain, perhaps, some physiological relation to the lungs.

OF THE LUNGS.

§ 172. The lungs consist of a structure exactly similar to that of a compound racemose gland, the lobes, lobules, and air-cells constituting the proper parenchyma; whilst the bronchia, trachea, and larynx represent the excretory apparatus. Considered as such a gland, the lung presents peculiarities both in function and structure: in function, since the process in the cells is one of absorption as well as excretion, and affects the entire mass of the blood; in structure, since the peculiar nature of the contents of the cells requires a special structure, firm and at the same time elastic.

§ 173. The *larynx* is the most complex part of the air-passages, and consists, firstly, of a firm framework, the *laryngeal cartilages* with their ligaments; secondly, of numerous small *muscles* attached to these; and lastly, of a *mucous membrane* full of glands, which lines its interior.

The *cartilages of the larynx* are not all alike in their structure, seeing that some consist of ordinary cartilaginous tissue, others of fibro-cartilage, and a third sort, again, are composed of the so-called *reticulated* or yellow cartilage. To the first kind belong the thyroid, cricoid, and arytenoid cartilages, all of which possess a homogeneous, hyaline matrix, with cartilage cells scattered through it (*fig. 157*). The affinities of these cartilages are especially with those of the ribs; at the exterior the cells are mostly flattened; proceeding inwards, there is a whitish layer of many large mother-cells in a more fibrous matrix; while internal to these, again, there is more of the matrix, and the cells are smaller and arranged in a radiating manner. The capsules of the cells are of considerable thickness, and, in the included cell, a large fat-globule is generally met with. Incrustations of the cartilage-cells and of the matrix by calcareous particles are very frequent in the laryngeal cartilages; and, in addition, true ossifications are also met with, which are always accompanied by the formation of cavities, filled with a beautiful gelatinous cartilage-medulla, containing vessels.—The epiglottis, the cartilages of *Santorini* and *Wrisberg*, and also, according to *Rheiner*, the *processus vocales* and apex of the arytenoid cartilage, consist of yellow or reticulated cartilage (see § 24, fig. 16). This presents, 1. dark fibres, very densely interwoven, which are much thicker in some animals than in man (in the ox, for example); and 2. large translucent cartilage-capsules, 0·01‴ to 0·02‴ in diameter. In one of these capsules *Henle* has observed a concentric disposition, of such a nature that the remains of the cell-cavity resembled a simple bone-lacuna, with a few processes from it (*Allg. Anat.*, tab. v. fig. 8).—The *cartilago triticea* consists of connective tissue with interspersed cartilage-cells, and is, therefore, ordinary fibro-cartilage, but it is occasionally only hyaline cartilage (*Rheiner, Ségond*).

With regard to the ligaments of the larynx, the *lig. crico-thyreoideum medium*, and *lig. thyreo-arytænoidea inferiora* contain principally elastic tissue, and are yellow; whilst the others, as the *thyreo-arytænoidea superiora, hyo-* and *thyreo-epiglottica*, with the *thyreo-hyoid* membrane, exhibit but little of the yellow elastic element. The elastic fibres of the laryngeal ligaments are of the finer kind, scarcely measuring above 0·001‴ in diameter, and are united, in the usual manner, to form a dense elastic network; this, however, even where it appears most pure, everywhere contains intermingled connective tissue. The *muscles* of the larynx are wholly composed of transversely striated muscular fibres, 0·016‴ to 0·024‴ in diameter, and of the same structure as elsewhere in the body. They arise from the cartilages of the larynx, and are attached to these as well as to its elastic ligaments. The attachment to a ligament is seen in the case of the *thyreo-arytænoideus*, which is, for the most part, lost upon the external concave side of the vocal cords.

The mucous membrane of the larynx, the continuation of the mucous membrane of the buccal cavity and fauces, is smooth, whitish-red, and connected with the subjacent parts by abundant submucous tissue of the ordinary kind. Except at the aperture of the glottis, the mucous membrane of the larynx possesses throughout a ciliated epithelium, and is without papillæ. It abounds in elastic fibres, which form a fine network, especially in its deeper portions; the more superficial layer, 0·03‴ to 0·04‴ in thickness, consisting chiefly of connective tissue, and terminating with a homogeneous border, of about 0·004‴ in thickness, that cannot be isolated. In adults, according to *Rheiner*, the *ciliated epithelium* begins at the base of the epiglottis and the upper vocal cords 2‴ to 3‴ below the entrance of the larynx, and thence extends downwards over the whole interior (see fig. 10, p. 36). It consists of several layers (see § 20, p. 36), and is, in the whole, from 0·024‴ to 0·04‴ thick. According to the discovery of *H. Rheiner*, which I can confirm, the vocal cords possess a laminated pavement epithelium, that extends as a narrow stripe upon the arytenoid cartilages as far as the pharynx. The proper cylinders, which carry the cilia, average 0·015‴ to 0·02‴ in length, and 0·0025‴ to 0·004‴ in breadth; they contain oval nuclei, of 0·003‴ to 0·0043‴ in diameter, with occasionally some fat-granules (fig. 156*). These cells are generally sharply pointed, and are frequently prolonged into a thin fibril, which may become so long that the whole cell acquires a length of 0·024‴ to 0·027‴. The *cilia vibratilia* are fine, clear, soft processes of the cells, 0·0016‴ to 0·0022‴ in length, which arise from them by a somewhat broader base, and terminate in a tapering point. They are mostly disposed close to one another over the entire terminal surface of the cells; according to *Valentin*, there are from ten to twenty-two upon each cell, an estimate which appears to me rather too low; more rarely, they are met with in smaller numbers, or even, as was previously mentioned, only a single one upon a cell. Care must be taken, however, not to mistake several cilia glued together for a single one, an appearance which is particularly likely to deceive in the fœtus. In a chemical point of view, the cells of the ciliated epithelium agree throughout with those of the cylindrical epithelium, and the spontaneous elevation of the cell-membrane, after the addition of water, is especially observable upon

Fig. 156*.

Isolated cells, from the ciliated epithelium of the larynx.

them. The cilia are more delicate than the cell-membranes, and very readily fall off on slight maceration of the epithelium. They are more or less altered by almost all re-agents, and by many are immediately destroyed; chromic acid, however, does not affect them much. When they have ceased to play, they may again be made to move actively for a while (as *Virchow* discovered) by the addition of diluted caustic potass or soda. In man, the ciliary movement proceeds, in the trachea, from below upwards, and is often perceptible fifty-two or even seventy-eight hours after death (*Biermer, Gosselin*). Desquamation of the ciliated epithelium of the larynx and air-passages is never presented normally. Separate ciliated cells, it is true, are occasionally detached, and discharged externally with the mucus of the air-tubes; but no traces of a more extensive detachment of the ciliated cells are met with. Even in diseases of the respiratory passages, the falling-off of the ciliated cells is by no means such a usual phenomenon as is believed by many, and the epithelium may frequently be found after death more or less uninjured amongst puriform mucus, and even in the midst of croupous exudation. The manner in which the fallen-off ciliated cylinders are replaced is, perhaps, simply by the multiplication of the deeper cells (by a process of partition of the cell), which move towards the surface, while cilia are reproduced on the most external. Probably, also, in desquamation the long cylinders may divide transversely, and new cilia may form on the surface so exposed, an opinion which receives confirmation from the observation of *Valentin* and *Biermer*, that many of these cylinders have two or three nuclei one behind the other.

The mucous membrane of the larynx contains a considerable number of small *glands*, which are all of the racemose kind. Like those of the oral cavity, of the pharynx, etc., they possess roundish gland-vesicles, of 0·03‴ to 0·04‴ in diameter, with a pavement-epithelium, and excretory ducts with cylindrical cells. Some of these glandules lie scattered upon the posterior surface of the epiglottis, where they are frequently imbedded in depressions of the cartilage, and in the cavity of the larynx itself, where their openings, the size of pins' heads, are readily visible to the naked eye. In these situations, their size is from $\frac{1}{10}$‴ to $\frac{1}{2}$‴ in diameter. Others of these racemose glandules form a large cluster at the entrance of the larynx, in front of the arytenoid cartilages, and a horizontal process from this cluster envelopes the cartilage of *Wrisberg*, while another portion descends into the cavity of the larynx (*glandulæ arytænoideæ laterales*). Glandules also lie upon the *arytænoideus* *transversus*, and a considerable number of them present themselves externally upon the ventricles of *Morgagni*, behind and above the ligaments of the ventricles. The secretion of these glands is pure mucus, without any morphological elements, as we have before seen in the glands of the buccal cavity.

The larynx is plentifully supplied with *vessels* and *nerves*. The former present, in the mucous membrane, the same condition as in the pharynx, and ultimately form a superficial net-work with capillaries of 0·003‴ to 0·004‴ in diameter. The *lymphatics* are numerous and proceed to the deeper cervical glands. With regard to the *nerves*, we learn from *Bidder-Volkmann*, that the special nerve of sensation, the *laryngeus superior*, contains fine nerve-fibres, and the special motor nerve, *laryngeus inferior*, much thicker ones. Their terminations are met with in the muscles, the perichondrium, and especially in the mucous membrane; they present the same arrangement in the last as in the pharynx (see p. 314), and upon the branches to the epiglottis, microscopic ganglia may be detected.

The glands of the larynx, and of the air-passages in general, are frequently altered in catarrhs, so that their vesicles measure up to 0·08‴ or even 0·15‴ in diameter, and are filled with small roundish cells, which are, perhaps, to be compared with the 'mucous corpuscles' formed upon the surfaces of mucous membranes.

Fig. 157.

Perpendicular section through the anterior wall of the human trachea; magnified 45 times. *a.* Fibrous envelope. *b c d.* Cartilage. *b.* External layer with flat cells. *d.* Internal layer with elongated elements. *e.* Submucous tissue. *f.* Part of a mucous gland. *g.* Elastic longitudinal fibrous layer. *h.* Epithelium, on which the cilia are not visible. *i.* Opening of a gland.

§ 174. The *trachea and its two branches* are connected with the neighbouring parts by a connective tissue, rich in beautiful elastic fibres, and are directly surrounded by a dense, elastic fibrous tissue. This layer covers the semi-circular cartilages as a perichondrium, connects the rings with each other, and, as a somewhat thinner layer, lines the posterior membranous wall of the canals. Next to this layer come the cartilages in front and at the sides, while posteriorly, the fibrous layer is in contact with a stratum of muscular fibres. The *cartilages* $\frac{1}{3}'''$ to $\frac{1}{2}'''$ in thickness, present quite the same characters as the larger laryngeal cartilages, except that they have no tendency to ossify. The *muscular fibres* of the trachea and its branches, on the other hand, differ in being no longer transversely striated. They form a layer of transverse fibres 0·3''' thick, upon the posterior wall of the canals, and also bundles of separate longitudinal fibres external to these. The component elements of these fibres measure 0·03''' in length, and 0·002''' to 0·004''' in breadth, and are connected in the form of small fasciculi. These bundles are inserted by beautiful little tendons of elastic tissue—partly into the inner surfaces of the extremities of the semi-circular cartilages, and partly (especially the longitudinal bundles), into the outer fibrous coat (see my *Micr. Anat.*, ii. 2, fig. 277).

Internal to the cartilages and muscular fibres, which in a certain manner are to be regarded as one layer, there follows a stratum of dense connective tissue, of about 0·12''' in thickness, and then the proper *mucous membrane*. The latter possesses two layers, an outer one of connective tissue 0·12''' thick, and an inner yellow layer 0·09''' to 0·1''' thick, almost purely composed of elastic fibres; these fibres measure up to 0·0015''' in diameter, and their reticulations run in the longitudinal direction: in some places, especially upon the posterior wall, they appear in the form of thick, flat bundles, frequently joining each other at acute angles. Upon the posterior wall especially, the innermost portion of this elastic layer is more like that of the larynx, being composed of connective tissue with fine elastic fibres; it can be separated from the coarser elastic layer as a thin pellicle 0·024''' to 0·03''' in thickness, and this itself is divisible into strata, one of which, immediately beneath the epithelium, is very homogeneous, and about 0·005''' in thickness. Upon them is seated the *ciliated epithelium*, which is laminated, and differs in nothing from that of the larynx. In the mucous membrane, there are numerous *glands*; those upon the anterior wall being smaller ($\frac{1}{10}'''$ to $\frac{1}{4}'''$), and immediately external to the elastic layer; those upon the posterior wall being larger ($\frac{1}{4}'''$ to 1'''), and situated external to the muscular fibres also. The larger of these glands differ in no respect from those of the larynx; but the smaller, situated in the substance of the mucous membrane, are often only simple or forked cul-de-sacs, composed of oval gland-vesicles (0·002‴ to 0·003‴ in diameter), and a very narrow aperture with thick walls (0·006‴ to 0·01‴), the appearance of thickness resulting from a beautiful cylindrical epithelium.

The *blood vessels* of the trachea are very numerous; those of the mucous membrane exhibit the peculiarity of the larger branches running chiefly in the longitudinal direction, while the net-work formed by the superficial capillaries, has roundish or angular meshes. This superficial net-work is frequently situated immediately beneath the homogeneous layer of the mucous membrane, external to the elastic elements. The trachea possesses a large number of *lymphatic-vessels*, whose mode of commencement is not known with certainty. That which I formerly described as such (*Micr. Anat* ii. 2, p. 307), was, probably, only some peculiar alteration in the blood-vessels (see *ibid.* p. 526). Numerous *nerves* also are found in the trachea, which have the same arrangement here as in the larynx.

§ 175. *Lungs.*—The lungs are two large compound racemose glands, in which there may be distinguished, 1, a special serous envelope, the *pleura*; 2, the secretory parenchyna, consisting of the *ramifications of the two bronchi,* with their terminations—the *air-cells,* together with numerous *vessels* and *nerves*; and, 3, an *interstitial tissue,* situated between these parts, and connecting them into larger and smaller lobules.

The *pleuræ* completely agree in their structure with the peritonæum; like this, they are thicker in their parietal lamina, and consist of connective tissue, richly furnished with elastic elements, some finer and some coarser, which tissue is covered by a pavement-epithelium. To these components is added, in the pleura covering the thoracic walls and the outside of the pericardium, a more purely fibrous layer. Vessels are seen in the pleura, most abundantly in that covering the lung, where they are furnished to the subserous tissue from the bronchial and pulmonary arteries; the parietal lamellæ are supplied more scantily by the intercostal and mammary vessels. *Luschka* has found *nerves* with fine and broad tubules, and has traced them in the outer part of the pleura to the phrenic nerve and the thoracic part of the sympathetic. I also have observed nerves in the pulmonary pleura of man, measuring up to 0·036‴ in diameter, and accompanying the bronchial arteries; they possessed nerve-tubes, some thick and others moderately fine, and here and there were interspersed large *ganglion-globules*, which came from the pulmonary plexus, and were probably given off chiefly by the vagus.—Peculiar appendages of the pleura, resembling the villi of the synovial membranes, and containing vessels and even nerves, occur here and there, according to *Luschka*, at the sharp edges of the lungs.

§ 176. *Bronchial-tubes and Air-cells.*—When the right and left bronchi have arrived at the roots of the lungs, they commence to ramify after the manner of the excretory ducts of a large gland; the liver for example. They become divided into smaller and smaller branches, mostly dichotomously and at acute angles; but small branches are also given off at right angles from the sides of the larger tubes. On reaching a certain size, all the bronchial tubes break up into tufts, and form a very thick tree, the finest ramifications of which never join each other. This extends throughout the whole lung, upon the surface and in the interior alike.

With the smallest bronchial tubes or *bronchia* are connected the ultimate elements of the air-passages—the air-cells or *pulmonary vesicles* (*vesiculæ s. cellulæ aëreæ s. Malpighianæ, alveoli pulmonum, Rossignol*). The terminal bronchial tube is connected with an entire group of vesicles, and not (as was formerly believed) by the ending of each in a single vesicle. The groups of vesicles correspond to the smallest lobules of racemose glands, and there is, accordingly, not the slightest necessity to designate them by another name, as *Rossignol* has done, who calls them 'infundibula.' Still it must be admitted, that their structure presents certain peculiarities. Thus, in other glands, the gland-vesicles have a certain independence, even if they are not entirely isolated; but the air-cells of the lung, which are the elements corresponding to gland-vesicles, are blended with each other to a considerable degree, so that the vesicles belonging to a lobule do not open separately into ramifications of the small bronchi, but join together into a common cavity, from which the air-passage is evolved. We

Fig. 158.

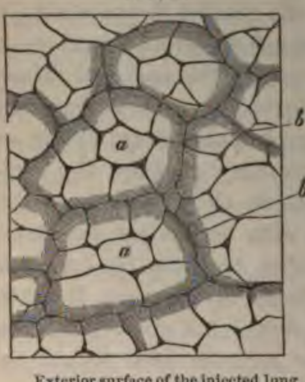
Two small pulmonary lobules, *a a*, with the air-cells, *b b*, and the finest bronchial branches, *c c*, on which air-cells are likewise seated, of a newly born infant; magnified 25 times. Half-diagrammatical figure.

may most readily convince ourselves of this arrangement, by making sections in different directions of an inflated and dried lung, or by examining a preparation which has been injected with coloured resin, and macerated in hydrochloric acid. In such preparations, we never find single terminal air-cells, nor do we ever see them pedunculated or opening independently; but they always open into each other, and coalesce in such a manner, as to form by their union a tube with sinuous walls, and mostly pyriform in shape. These tubes are the finest pulmonary lobules, or the infundibula of *Rossignol*. The air-cells on their walls are not disposed singly and at regular intervals, but are arranged in groups, and even form small secondary recesses, which open in the so-called infundibulum. An idea of the whole relation of the parts in question may be best obtained, by regarding each pulmonary lobule as an amphibian lung in miniature: or we may consider the ultimate divisions of the bronchia to widen at their ends, and the dilated extremities to be closely beset with numerous racemose groups of vesicles, opening into one another, and into the common cavity. This structure corresponds, then, in its main features with that of other racemose glands. *Adriani* has observed in the adult lung, a partial coalescence of the air-cells of a lobule by perforation of their walls, the septum between two adjacent air-cells in a group being reduced to a few isolated threads.

The smallest bronchial tubes, $0{\cdot}1'''$ to $0{\cdot}16'''$ in diameter, arise from the finest lobules by simple diminution in size. At their origin they continue to be surrounded by simple air-cells, which are called *parietal*, and they, accordingly, have at first sinuous walls. The irregularities soon disappear, and give place to the ordinary smooth appearance, which is observable through the remainder of their course. The *size* of the air-cells varies very considerably even in healthy lungs, and, in the absence of dilatation by air, is found to measure after death $\frac{1}{6}'''$ to $\frac{1}{10}'''$ to $\frac{1}{18}'''$. Every air-vesicle, however, is capable, by virtue of its elasticity, of being distended, without tearing, to double or treble its original size, and of returning afterwards to its previous condition. We shall not err in assuming, that in life, during moderate fulness of the lungs, the air-vesicles are at least one-third wider than after death; and that, by the utmost possible deep inspiration, the dilatation may reach to double the size presented *post mortem*. In emphysema, dilatation to this extent, and even far beyond it, becomes permanent, and may lead at last to the rupture of the walls of the alveoli of a lobule, or even to the coalescence of the lobules themselves. In a recent collapsed lung, the *form* of the air-cells is mostly roundish or oblong, becoming polyhedral, in an inflated or injected lung, in consequence of their mutual flattening; the air-cells of the surface of the lungs invariably appear polygonal, and their external sides are always nearly equal.

The *lobulated structure* of the lung is not nearly so distinct in the adult as in younger individuals and in animals. It is, therefore, advisable to begin the investigation of this structure on the lung of a child. Here each single lobule is to be found distinctly separated from all others by connective tissue, and may be isolated, so as to exhibit the tolerably regular pyramidal form of the superficial lobules, and the more irregular shape of the internal ones. In the adult, these ultimate lobules, ranging in size from ¼‴ to 1‴, are still present, but are so intimately blended, that even upon the surface of the lung their outlines are difficult of recognition; while in the interior of the organ, the structure formed by their union appears at first sight homogeneous, somewhat as in the liver.

Fig. 159.



Exterior surface of the injected lung of a cow, after *Harting*; magnified 30 times. *a a*, Air-cells. *b b*, Borders of the smallest lobules or infundibula (*Rossignol*).

On the other hand, the secondary lobules, ¼, ½, to 1 inch in size ('lobules' of some authors), are generally distinct, even in adults, especially when the boundaries of these lobules are marked out by streaks of pigment deposited in the interjacent connective tissue, as is often the case in grown persons. These lobules last mentioned, united by an abundant interstitial tissue, make up the well-known large 'lobes' of the lung. Thus the lung, as a whole, is composed of larger and smaller segments, which again are made up of air-cells and minute bronchia. Each of these segments is in connexion with one, and one only, of the larger bronchial tubes, which have arisen from the main air-passages in certain definite groups.

§ 177. The *intimate structure* of the bronchi and air-cells is as follows.—The *bronchi* are, in the main, constructed like the trachea and its branches; still some differences present themselves even from the commencement, and these increase more and more as the bronchia are traced onwards. Two coats may, for the sake of convenience, be distinguished upon them: an outer *fibrous coat*, partly possessing *cartilages,* and a *mucous coat,* in which is a *layer of smooth muscular fibres.* The outer coat, formed of connective tissue and elastic fibrils, is as thick on the first bronchia within the lung as in the two main bronchi from which they spring. It becomes, however, gradually more and more attenuated, and is scarcely demonstrable with the knife on bronchi below $\frac{1}{2}'''$ in diameter. Traced onwards, this coat is found to coalesce eventually with the mucous membrane and the loose connective tissue, which connects the bronchi with the pulmonary parenchyma. In it are seated the cartilages of the bronchia, which, instead of semicircles, are here irregular angular plates, distributed over all parts of the circumference of the tube. These plates are at first large and closely disposed, but become further apart from each other where the bronchial tubes send off branches, becoming progressively smaller and smaller, till at length they disappear from bronchia below $\frac{1}{2}'''$ in diameter. This is certainly the rule; but *Gerlach* believes he has seen them upon bronchia $\frac{1}{10}'''$ in diameter. These cartilages are not unfrequently reddish, and their structure, at first, exactly resembles that of the tracheal rings; as the cartilages become smaller, the differences between the superficial and deeper cells disappear, and the tissue becomes alike throughout, and resembles the interior portion of the larger cartilages. The *muscular fibres* are observed in bronchia of all sizes, forming flat fasciculi, which completely encircle the tube, and form a perfectly unbroken layer; in very old people, however, spaces are found to exist between the fibres. These muscular fibres have been observed upon branches $\frac{1}{10}'''$ to $\frac{1}{12}'''$ in diameter, and, therefore, probably occur even up to the pulmonary lobules.—Intimately connected with the muscular coat is the *mucous membrane,* which, at first, has the same thickness as in the trachea; but this, like the other component coats, gradually becomes attenuated, so that bronchia below half a line in diameter have altogether only a very thin wall. At its attached surface, this membrane is composed throughout of elastic longitudinal fibres, whose bundles give to the inner surface of the bronchi the characteristic longitudinally striped appearance, and also give rise to a longitudinal folding of the mucous membrane more or less distinct. Secondly, there is a homogeneous layer, 0·002''' to 0·003''' in thickness, on which is situated, thirdly, the *ciliated epithelium.* This epithelium in the larger bronchia, as far as those of 1''' in diameter, is composed of several layers, but gradually becomes reduced to a single layer of ciliated cells, 0·006''' in length (*fig.* 8, p. 36).—The bronchial tubes possess, at first, numerous racemose glands, which, however, disappear upon canals of 1‴ to 1½‴ in diameter, although *Remak* says he has seen them in the walls of the finest bronchia just before they enter the ultimate lobules.

Pulmonary Vesicles.—In these we may demonstrate the existence of two layers, the one fibrous, the other epithelial; and I am not prepared to admit that there are any other coats than these. The *fibrous* coat is obviously continued from the bronchia, and consists of the mucous membrane, which has become very thin and conjoined with the fibrous layer. This coat is completely destitute of smooth muscular fibres, and consists of a homogeneous stratum of connective tissue, together with elastic fibres and numerous vessels. The *elastic fibres* (0·0005‴ to 0·002‴) appear chiefly in the form of separate trabeculæ and stripes, coursing upon the borders of air-cells and around their openings; they anastomose in all directions with each other, and they form a firm framework, between which the softer vascular parts of the alveoli are stretched. These elastic trabeculæ are generally composed of yellow fibres, arranged as closely as possible, the meshes of the network appearing only as very narrow fissures, so that it is difficult to recognise the nature of the tissue we are observing; but sometimes the fibres are more loosely connected, and then their elements are distinct. The trabeculæ meet and coalesce with each other around the pulmonary vesicles, so that the boundaries of the separate air-cells are rarely to be distinguished. A few elastic fibres of the finer kind also proceed from the trabeculæ into the remaining walls of the pulmonary vesicles, and become connected therein to form a wide network. The *connective* tissue of the air-cells, which appears perfectly homogeneous, gives place to the elastic elements and vessels, where these are in large quantity, and comes to view, so to speak, only in the walls of the alveoli, between the elastic trabeculæ, serving to connect the numerous capillaries.

Fig. 160.

A human pulmonary vesicle, with the parts adjoining: magnified 350 times. *a.* Epithelium. *b.* Elastic trabeculæ. *c.* More delicate walls between the trabeculæ, with fine elastic fibres.

The *epithelium* of the pulmonary vesicles is an ordinary pavement-epithelium without cilia, which forms a single layer, and rests immediately on the fibrous coat. Its cells measure 0·005‴ to 0·007‴ in diameter, and 0·003‴ to 0·004‴ in thickness; they are pale, granular, and polygonal, in disease sometimes containing fat-granules. A regular desquamation of this epithelium has been stated to take place by some authors, but with as little evidence here as in the trachea and bronchi. It is true, that single cells of this epithelium may become mingled with the bronchial mucus, whether by accident or by disease, and, after death, the epithelium of the air-cells in man is frequently found free inside the air-cells and in the finest bronchia; but the epithelium may be observed *in situ* in some alveoli in almost every human lung, while, in newly killed animals, there is not the slightest difficulty in observing this membrane in its normal position.

The *interlobular connective tissue* of the lung is scanty, even between the secondary lobules, and between the primary or ultimate lobules it exists in exceedingly small quantity. It consists of ordinary connective tissue with fine elastic fibres, and contains, in the adult, more or less of a *blackish pigment*, in the form of small granules, disposed irregularly and in masses; crystals of pigment may also be found, and these are never included in cells. The walls of the alveoli themselves also very frequently contain this pigment, which, when it is deposited regularly and in small quantities, allows the contours of the secondary lobules, and frequently even those of the primary, to stand out very beautifully.

The existence of an epithelium in the air-cells has recently been disputed by *Rainey*, as well as by *Mandl* (*Micr. Anat.*, ii. p. 327), and *Ecker*. On the other hand, *Radclyffe Hall*, and *Brittan* have observed it in reptiles, mammalian animals, and in man; *Black* (*Monthly Journal*, 1853, p. 2) and *Williams* also confirm its existence in man.

§ 178. *Vessels and Nerves of the Lungs.*—The lungs stand quite by themselves in the disposition of their blood-vessels, possessing two complete systems of vessels which are, for the most part, wholly distinct from each other. They are, the system of the *bronchial* vessels, for the nourishment of certain parts of their structure, and the system of *pulmonary* vessels, for the performance of the special functions of the organs. The branches of the pulmonary artery generally follow the bronchia, and lie above and in front of these tubes. They also divide in a dichotomous manner, but more frequently than the bronchia, and they therefore diminish more rapidly in calibre. At length, arrived at the secondary pulmonary lobules, a branch is given off for the supply of each; this divides into still finer twigs, which usually correspond in number to the smallest lobules, and thus at last the separate air-cells are supplied. The course of these finest 'lobular' arteries, as they are called, can be very readily traced in a preparation which has been injected, inflated, and dried. Where these vessels extend into the tissue uniting the lobules (*infundibula*), they are seen to supply not one lobule only, but always two or three lobules with fine twigs. These penetrate inwards, upon and between the air-vesicles, divide several times during their course among the thick elastic trabeculæ, and occasionally also join each other, or unite with twigs of adjacent vessels, though not in any regular manner. Lastly, the lobular arteries break up into the *capillary network* of the pulmonary vesicles. In a moist preparation the meshes are seen to be roundish or oblong, and only 0·002‴ to 0·008‴ in width, while the vessels are 0·003‴ to 0·005‴ in diameter; and the plexus is, therefore, one of the closest which occur in the human body. The network of capillaries runs through the fibrous tissue in the walls of the air-cells, and is removed about 0·001‴ from the epithelium; it extends continuously over all the alveoli of an ultimate lobule, and is partially connected, also, at least in the adult, with the plexus on neighbouring lobules. The *pulmonary veins* arise from the above-mentioned capillary network by means of roots, which lie external to the arteries upon the smallest lobules; they run between the latter, and join with other lobular veins to form larger trunks, which extend through the pulmonary parenchyma, partly with the arteries and bronchia, and partly isolated from them.

Fig. 161.

Capillary network of the pulmonary vesicles of man. Magnified 60 times.

The *bronchial arteries* are distributed, firstly, to the larger bronchial tubes, whose vessels present the same conditions as in the trachea; secondly, upon the pulmonary veins and arteries, the latter of which more especially possess an extremely rich vascular network, which can be traced upon branches of $\frac{1}{3}$‴ and less in diameter; lastly, to the pulmonary pleura, the twigs for which go off, partly at the hilus and in the fissures between the main lobes, partly arise between the secondary lobules from the vessels accompanying the bronchia. Small independent vessels, which do not arise from the bronchial arteries, may also be traced along the pulmonary ligaments to the pleura.

The *lymphatics* of the lung are very numerous. The superficial ones run in the subserous connective tissue, in the interspaces of the larger and smaller lobules, and form a network, of which the superficial meshes are finer; and the deeper, coarser and angular. This plexus covers the whole surface of the lung, and discharges itself by means of special superficial trunks, which converge to the root of the lung, following the course of the blood-vessels; and the superficial plexus has also a connexion with the deeper vessels by means of numerous trunklets, which pass inwards between the lobules. These deeper lymphatics arise from the walls of the bronchia and blood-vessels, especially those of the pulmonary arteries, and run with these canals through the pulmonary substance, and through some small lymphatic glands (*glandulæ pulmonales*), to the root of the lung, where they join the larger bronchial glands.

The *nerves* of the lungs arise from the vagus and sympathetic, form the small anterior and the large posterior pulmonary plexuses, and are especially distributed with the bronchia and the pulmonary artery, although here and there they also accompany the pulmonary veins and the bronchial vessels. They are furnished with microscopic ganglia in the interior of the lung, and can be followed to near the terminations of the bronchial tubes.

It is worthy of observation, that in addition to the air-vesicles, some other parts in the lungs are supplied by the pulmonary vessels, viz., the *surface of the lung* and the *finer bronchia*. With regard to the former, there are seen at different places, upon an uninjected lung, small branches of the pulmonary artery passing to the surface of the lung, and ramifying beneath the pleura. *Reisseisen* (p. 17) describes these vessels, and gives very beautiful drawings of them (tab. iv. v.); and recently, *Adriani* has followed them in injected lungs, and states that they describe a tortuous course and frequently anastomose, being here considerably thicker, and forming wider networks than the vessels of the alveoli. The blood of these networks is drawn off by superficial roots of the pulmonary veins on the one hand, and on the other hand, by anastomoses with the expansion of the bronchial vessels on the pulmonary pleura. That the pulmonary arteries also supply the bronchia in part, had been already mentioned by *Arnold* (*Anat.* ii. 171); and we are indebted to *Adriani* for more particular information on this interesting subject. According to him, the pulmonary arteries and the pulmonary veins are the vessels chiefly concerned in the formation of the capillary network on the surface of the bronchia. This plexus is distinguished by the elongated form of its meshes, while its vessels are almost as narrow as on the air-cells, measuring in man 0·004‴ to 0·006‴ in diameter. The bronchial vessels in this situation appear to supply more especially the muscular and fibrous coats of these canals. As may be easily understood, the two systems of vessels have here a certain connection between each other, and, accordingly, the older anatomists, as *Haller, Sömmering*, and *Reisseisen*, are quite right when they speak of a connection between the two systems of vessels. According to *Adriani* and *Rossignol*, the bronchial arteries and veins can be injected from the pulmonary veins, and *vice versa*, the pulmonary veins from the bronchial arteries, although the bronchial vessels cannot be injected from the pulmonary arteries.

Supported by these facts, we are justified in ascribing to the finest bronchia a share in the process of exchange of gases in respiration, although, on account of the somewhat greater thickness of the epithelium, and the somewhat wider capillary network of the fine air-tubes, their share must be inferior to that of the pulmonary vesicles. We may also make mention here of the enlargement of the bronchial arteries, and of the extension of their region of distribution in cases of disturbance of the circulation in the pulmonary arteries (compare VIRCHOW, in his *Archiv.*, iii. 3, p. 456). Here the bronchial arteries frequently replace whole branches of the pulmonary arteries, and become actual respiratory vessels; conditions which are readily explained by the occurrence of numerous normal anastomoses between the two systems of vessels. Very recently, *Beau* has maintained that the pulmonary arteries supply the mucous membranes of all the bronchial tubes, even up to the trachea.

§ 179. *Development of the Lungs.*—In mammalia, the lungs appear somewhat after the liver, as two hollow protrusions of the anterior pharyngeal wall, situated close to each other. They soon become furnished with a common pedicle—the rudiment of the larynx and trachea—in the construction of which the epithelial lining and the fibrous coat of the pharynx are equally concerned. Developing further, the terminations of the two primitive protrusions give out a number of processes, which constantly increase by ramification, and differ from those observed in most other glands, in being always hollow from their commencement onwards. In the sixth month, the pulmonary vesicles develop from the dilated, club-shaped extremities of these processes. During the growth of the gland-elements, the inner epithelial layer extends itself by independent multiplication of its cylindrical cells (probably by a process of partition); whilst at the same time, the surrounding fibrous layer continues also to grow independently, and this layer eventually gives rise to the fibrous coats of the bronchia and air-cells, together with the vessels and nerves. In the human embryo, the large pulmonary lobules are formed in the second month, and besides these, smaller segments may be distinguished (0·16‴ in size), which arise from the extremities of bronchia, after these have become already considerably ramified. To these segments I have given the name of gland-granules (in ECKER, Icon. Phys., tab. x., fig. 7). In the growth of the fœtus, these granules become more and more numerous with the multiplication of the bronchial ramifications; and in the fifth month they touch each other, and form small lobules, of 0·24‴ to 0·48‴ in diameter, each of which has probably arisen from a single gland-granule, or bronchial termination of the second month. These small lobules at first correspond to the secondary lobules of the perfect lung; the primary or ultimate lobules with the air-vesicles themselves are produced by a process of budding from the gland-granule. The ultimate alveoli are first seen in the sixth month of fœtal life, and new alveoli are continually being added up to the period of birth (see my *Micr. Anat.*, ii. 2, p. 323). In newly-born infants, the secondary lobules measure 2‴, 3‴ to 4‴, and the alveoli 0·03‴, before they are filled with air; after the first inspiration, they increase to 0·035‴, 0·04‴ to 0·06‴ in diameter. The alveoli appear to be of the same number in the infant as the adult, and the further enlargement of the lungs seems to take place only by the progressive growth of all their parts.

The *investigation* of the lungs should present difficulty only with regard to one point, viz., the relation of the pulmonary cells to the termination of the bronchia; but the difficulties here are really very considerable. In fresh preparations, the air-cells are seen to communicate very freely, and they are found at the ends of the bronchia in lateral groups, and not terminally only. If it be desired to investigate the relation thoroughly, we make use of lungs inflated and dried (it is better to tie off one end of an inflated lung and dry it separately). Preparations formed by corrosion after injection, or lungs injected with a colourless material (as wax and turpentine), must also be examined; and in all these ways together, we shall arrive at some definite result.

Before injecting the bronchi, the air must be drawn out by an air-pump, or a well-acting syringe may be employed, although less adapted for this purpose. The injection of the blood-vessels is not attended with any difficulty; and moist preparations, injected partly with some opaque substance, partly with transparent materials (the process of *Schröder* and *Harting*), such as Prussian blue, are to be preferred to dried preparations. The air-cells themselves, the bronchi, the larynx, and trachea, can be easily examined. The epithelium of the pulmonary vesicles, and also ciliated cells, are obtained isolated in large quantities in every section through the lung. If it be desired to study the alveoli, the air must previously be carefully removed. They are most beautiful in man, in whom, also, all the other parts, as the cartilages, elastic elements, muscular fibres, and glands, are readily accessible.

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OF THE THYROID GLAND.

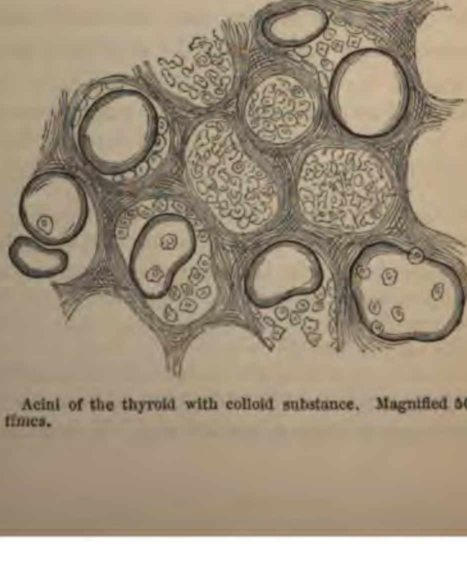
§ 180. The thyroid gland is one of the so-called 'ductless glands,' and bears in its external appearance a considerable resemblance to the racemose glands. Its gland-vesicles are round shut sacs, measuring from 0·02‴ to 0·05‴, which are held together in lobules by a fibrous stroma. The lobules thus formed, the gland-granules of some authors, are roundish or oval, or somewhat polygonal, and measure ¼‴ to ½‴. These elements unite into larger lobes, and these again congregate into still larger divisions, which are seen on the surface of the organ. These divisions are bounded by a special envelope of some thickness, which is connected with a fibrous coat enclosing the whole gland.

With reference to its intimate structure, there is not much to be said about the fibrous tissue, or stroma of the thyroid, for it consists of ordinary interwoven bundles of connective tissue, mingled with fine elastic fibres. A certain number of fat-cells are also found upon the surface. The *gland-vesicles* themselves present such an inconstant structure in the human thyroid, that it is not easy to say what is properly normal. According to my own observations in man and in the lower animals, they appear to consist of a *membrana propria*, an epithelium, and fluid contents, like the true gland-vesicles, of the mucous glands for instance. The *membrane* is quite homogeneous, clear, and delicate, 0·0008‴ in thickness; like all such membranes, it swells up and comes out more distinctly on the addition of caustic alkalies. Upon the inner side of the membrane is situated a simple layer of epithelium, composed of polygonal, finely granular, clear cells, of 0·004‴ to 0·006‴ in diameter, with simple nuclei. The cavity enclosed by these cells is filled with a clear, somewhat yellowish viscid fluid, whose behaviour with alcohol and nitric acid, or on the application of heat, clearly shows the presence of a large quantity of albumen. Such, then, are the contents of the gland-vesicles in the healthy human thyroid, particularly in that of children; but let the organ be but a little altered, and numerous other conditions make their appearance. Very frequently there is found, instead of a regular epithelium, nothing but a fluid mingled with small clear and dark granules and free nuclei. However, it is very possible this peculiarity of the contents is the result of *post mortem* change, rather than of disease; for a transitional state may be observed where epithelial cells, bleached and half dissolved, are found free in the interior of the vesicles. On the other hand, we meet with a condition which is, beyond doubt, pathological, consisting in the transformation of the thyroid and its vesicles into 'colloid.' Early stages of this degeneration, however, are so common, that many writers have described it among the physiological appearances. The change consists in the development of colloid substance in the interior of enlarged gland-vesicles. The colloid itself forms transparent amorphous masses, softish and yellowish, like the same substance met with elsewhere. In the slighter grades of this alteration, the vesicles

Fig. 162.

Some gland-vesicles from the thyroid gland of a child; magnified 250 times. *a.* Areolar tissue between the same. *b.* Membrane of the vesicles. *c.* Their epithelium.

Fig. 163.



Acini of the thyroid with colloid substance. Magnified 50 times.

are only a little enlarged, up to 0·05‴ in diameter, appearing upon section as transparent, yellowish-white spots or granules which *Ecker* aptly compares with boiled sago, the structure being otherwise unchanged. In the higher grades of the disease, the vesicles containing the colloid substance become converted into larger cysts, $\frac{1}{10}$‴ to $\frac{1}{2}$‴ in diameter, in which the epithelium is rarely any longer distinct, although nuclei and pale roundish cells (the latter granular or filled with nuclei) may occur in the cysts along with their abnormal contents. These cysts displace the stroma by their growth, and enlarge also by partial absorption of the walls of the original vesicles. Thus, at length, they coalesce to form still larger sinuous cavities, whose contents are frequently altered in various ways by extravasation, and the metamorphoses consequent thereon. In the lower mammalia, and in birds also, the thyroid occasionally exhibits gland-vesicles slightly distended with colloid matter.

The *blood-vessels* of the thyroid are, it is well known, disproportionately numerous, but otherwise they present, in their coarser ramifications, nothing worthy of remark. Each lobule receives some small arteries, which, breaking up into subordinate branches, are distributed in the stroma between the vesicles, and, at length, form around each of them a beautiful capillary network, resembling that of the pulmonary vesicles, but with wider meshes. The vessels of the network measure 0·003‴ to 0·005‴ in diameter, and the interspaces, which are roundish, angular, or elongated, measure from 0·008‴ to 0·016‴. The veins arising from this network only partly follow the course of the arteries, and they exceed the latter in number. *Lymphatics* also occur in considerable numbers in the thyroid, but their relations in the interior are unknown. Finally, the *nerves* are scanty, and are only those which belong to the vessels; they come from the cervical part of the sympathetic.

Besides the degeneration of the glandular elements, which has been described, there is another kind of pathological change frequently observed, which results in the production of vascular bronchocele. Here, in addition to a hyperæmic condition, numerous aneurismal enlargements are found on small vessels of 0·03‴ to 0·04‴ in diameter, which are regarded by *Ecker* as arteries or coarse capillaries. By the bursting of such enlargements, there subsequently arise apopletic cysts of different sizes. These cysts and their contained blood may then undergo a variety of metamorphoses, new effusions and exudations being added, and normal tissue becoming also implicated. In the vascular bronchocele, *Ecker* frequently found also a calcification of the walls of the smaller vessels, numerous calcareous granules dotting their surface, or, in a more advanced stage, obliterating their calibre altogether, so that they appeared like white concretions; this took place alike in the dilated vessels and in those of normal size. In a certain form of goitre, *Rokitansky* describes a hypertrophy of the thyroid by multiplication of the normal elements of the gland, new vesicles arising partly independently, partly by internal growth from the walls of enlarged vesicles.

According to *Remak*, the thyroid body is developed by the separation of a part of the anterior wall by the gullet, and division of this into two halves. In a human embryo at the third month, I found the thyroid already composed of isolated vesicles, 0·016‴ to 0·05‴ in diameter, which consisted of a homogeneous envelope, including roundish or angular cells. I think that I have seen these follicles multiply by sending out roundish processes, which afterwards separate. If this be really the case, the whole process of formation of the thyroid may, perhaps, be regarded as a continued growth and division of the follicles; the division of its primitive vascular rudiment, as observed by *Remak*, being only the first phase of it. In this way, a certain resemblance to the thymus would also be established, only that in the thymus the two first rudimentary processes, as well as subsequent ones, become severed from each other, and only retain a slight connection. According to the above view, the follicles of the thyroid are not enlarged cells, still less are they metamorphosed nuclei (*Rokitansky*), but they have the value of true gland-follicles.

In the *investigation* of the vesicles of the thyroid, the organ should be examined in children, and in the lower animals, in birds and amphibia especially. Sections made with the double knife are best adapted for the study of the disposition of the vessels, and of their relation to each other; but this object may also be attained by carefully teasing out the parts under the microscope. The vessels may be very easily and completely injected in children. The network of capillaries around the vesicles is best seen in sections near the surface.

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OF THE THYMUS.

§ 181. The thymus is another of the so-called 'vascular glands.' It is a double, elongated organ, flattened and broader inferiorly, and is enveloped and connected with neighbouring parts by loose connective tissue. Even on superficial examination, we may see larger lobules, averaging from 2‴ to 5‴ in size, and having a roundish, oblong, or pyriform shape, mostly compressed against each other. These lobes are only connected by yielding connective tissue, and can be separated without difficulty. Tracing the lobes to their inner attachment, they are all found to be attached singly to a common stalk, in the interior of which is a canal. This duct runs through the middle of the gland, and usually presents an irregularly spiral arrangement; its diameter is $\frac{1}{2}'''$ to $1\frac{1}{2}'''$. On opening the canal, we find upon its inner surface a great number of oblong or fissure-shaped openings, each of which leads into a lobule, and constitutes the outlet of a cavity in the latter. This 'thymus-canal,' with the lobules opening into it, presents an obvious resemblance to the excretory duct and the lobules of a true gland; and the similarity is increased by the circumstance, that the lobules consist of smaller subdivisions, which are likewise hollow, and then, again, of roundish bodies ($\frac{1}{5}'''$ to $\frac{1}{3}'''$), the gland-granules (or acini of authors), which are the analogues of gland-vesicles of true glands. These elements may be recognised externally upon the lobules, and, by their polygonal form, they give to the surface a beautiful mosaic-work appearance, resembling that of the lungs. These gland-granules, however, are solid bodies, and are not vesicular, like the air-cells of the lungs, although, otherwise, their affinities are with these rather than with any other true glandular element. These gland-granules are intimately united together immediately around the cavity of the lobule, but on its surface they are separated from each other. Thus each *lobule* may be considered as a thick-walled vesicle furnished with dilatations, the inner surface of which is even and undivided, whilst the outer is separated by fissures, more or less deep, into the above-mentioned gland-granules.

Fig. 164.

A piece of the thymus of the calf, spread out. *a.* Chief canal. *b.* Lobules. *c.* Isolated gland-granules, seated upon the principal canal. Natural size.

In many cases, a deviation from the conditions just described is met with, when the thymus, instead of a narrow canal, into which the cavities of the lobules open, contains an actual elongated cavity, $\frac{1}{2}'''$ to $1'''$ in breadth, with which the lobules communicate by large fissure-shaped openings. Many anatomists, and, among the modern, *A. Cooper* especially, regard the presence of the cavity as normal; whilst others, with *Simon* at their head, are inclined to view it as produced by the manner in which the gland is examined (injection, or blowing-in of air). For my own part, I must concur with *Simon*, to the extent of asserting that the injection, or blowing-up of such a delicate structure as the thymus, must lead to error, if not performed with the greatest precaution; and I am further convinced, that many of the so-called 'reservoirs' observed in the thymus have been made artificially only. Nevertheless, I am of opinion that thymus glands really occur which, during life, contain a large central cavity, since I have seen such a cavity in cases where no kind of preparation or injection was practised, and here it has extended through the whole thymus, or only through separate sections of it. I hold the occurrence of a narrow central canal to be the normal and usual condition; but I believe that, in certain cases, it may become dilated by a more abundant formation of the secretion, and ultimately be converted into a large cavity.

In a very meritorious work on the structure of the thymus, *Jendrassik* has advanced the doctrine that it is originally made up of isolated lobules, which only become conjoined subsequently and in particular cases. But by an examination of the thymus of mammalia, especially of the calf, this view may be shown to be wholly untenable; and the study of the development of the gland is also fatal to such a supposition. Such investigations will demonstrate readily and conclusively the existence of a single branching central cavity, such as I have described (see also my *Micr. Anat.*, ii. 2, fig. 294).

Fig. 165.

Transverse section through the apex of an injected lobule of the thymus of a child; magnified 30 times. *a*. Envelope of the lobule. *b*. Membrane of the acini. *c*. Cavity of the lobule, from which the large vessels ramify into the acini, and partly terminate with loops upon the surface of them.

§ 182. *Intimate Structure of the Thymus.* — The connective tissue which envelopes the thymus has the same characters as elsewhere; it contains fine elastic fibres, and frequently interspersed fat-cells. If it be removed from a lobule, the outer surface, fissured between the individual acini, comes to view. By strong magnifying powers, there is here seen a very thin membrane (0·0005‴ to 0·001‴ in thickness), indistinctly striated or almost homogeneous, which has been well described by *Simon*. This belongs to an entire lobule, or even surrounds the whole gland continuously, and is to be regarded in the same category as the wall of the follicles of the Peyerian patches, of the tonsils, etc. Within this envelope, between it and the cavity of the lobule, there is situated a greyish-white, soft, delicate substance, $\frac{1}{8}'''$ to $\frac{1}{3}'''$ in thickness, which, examined microscopically, appears to consist of nothing but free nuclei and small cells, and hence has hitherto been unanimously regarded by all observers as the secretion of the supposed gland-vesicles. This substance, however, cannot be washed off, as would be the case if it lay loosely in the space surrounded by the delicate envelope, but, rather, it presents a considerable degree of toughness and resistance. If it be more narrowly investigated, it is gradually perceived that other elements besides these, in part of quite an unexpected kind, enter into its composition; these are *blood-vessels,* and a small quantity of a fibrous substance like connective tissue, so that we are here presented with a structure not dissimilar from that of the contents of the Peyerian follicles.

With regard to the structure of the walls of the lobules, the chief mass is composed of the foregoing pseudo-vesicular elements, together with a small quantity of fluid connecting them. The constituents of these are, first, round or flattish nuclei, measuring 0·002‴ to 0·005‴, with clear, homogeneous contents, and with or without nucleoli; these nuclei are always met with in large numbers; by the addition of caustic soda, or acetic acid, their contents become granular and turbid. Secondly, cells are found; and I believe with *Ecker* and *Jendrassik*, in opposition to *Simon*, that these are never absent. They are of very various sizes (0·004‴ to 0·01‴), and although they vary in number, still they are always much more scanty than the nuclei. Their nuclei are generally simple and distinct, and their contents are either pale or are composed of scattered fat-granules, or else the cells are destitute of a nucleus, and entirely filled with fat. This last condition *Ecker* states he has observed after the complete formation of the organ. Through the midst of these elements there run a great number of larger and smaller blood-vessels. The main vessels running external to, but close upon the central cavity in the longitudinal direction of the organ, give off branches especially to the central cavity, which penetrate its walls, and arrive at its *inner surface.* Here they ramify and anastomose, and form a moderately dense network of capillaries, which are contained in a delicate membrane of connective tissue. From this arterial network numerous vessels are distributed to the substance of the lobule, especially from the point where its cavity joins the main canal; and these vessels run in the tissue of the thick walls of the lobule, ramifying ultimately on the surface of the separate acini, where they form a very close capillary network, with vessels measuring 0·003‴ to 0·005‴, and interstices of 0·01‴ to 0·02‴. In man, the expansion of these vessels is situated so entirely in the interior of the acini, that, even when distended to the utmost, not a single vessel is to be met with upon the outer side of their enveloping membrane, but they all terminate in loops close beneath it. Besides these blood-vessels, a small quantity of *connective tissue* seems to enter into the composition of the thick walls of the acini; at least, there is often found in their intimate structure a tolerably distinct membrane supporting the larger vessels, and being analogous to that which lines the central cavity. In other cases, in animals especially, no inner limiting membrane can be demonstrated, and the cavities of the lobules are directly bounded by the granular substance uniting the vessels, while there is no trace of any fibre, except a few delicate striæ between the vessels. In no case do we find an epithelium lining the cavities, and, accordingly, no comparison can properly be made between the innermost parts of their walls and a mucous membrane.

The *common cavity*, or *central canal* of the thymus, has the same structure as the lobules, except that externally the fibrous layer is thicker, and that internally we meet with a thinner granular layer, with rather large vessels. In a fully developed thymus, the central cavity contains, like all the accessory ones, a greyish-white or milky fluid, of slightly acid reaction. This is often found in large quantity, and in it, along with a clear juice rich in albumen, there are contained numerous nuclei, separate cells, and, under certain circumstances, concentric bodies (see below). The *lymphatics* of the thymus are numerous, and the *nerves* can be readily demonstrated upon its arteries, although they cannot be traced to their terminations.

Jendrassik, who confirms my results in most points, believes that the arteries spread out into capillaries immediately after their entrance into the acini. He regards the greater part, if not the whole, of the vessels on the wall of the cavity of the lobule as of the nature of veins, and I am willing to believe that he may be right; it is certain, however, that vessels, which are arteries, do proceed from the interior to the surface of the acini. *Friedleben* has revived and confirmed an observation of *Rostelli*, according to which the blood of the thymic vein contains a large quantity of the microscopic elements of the gland-juice.

Besides the above-described normal elements, there are found, especially at the period of the involution of the organ, other peculiar round structures which I will call, with *Ecker*, the *concentric bodies* of the thymus. They appear in very various forms, which may, I think, be conveniently reduced to two. The first form consists of *simple* bodies, of 0·006‴ to 0·01‴ in size, whose envelope is thick and concentrically striated, while their contents, ordinarily granular, have sometimes the appearance of a nucleus, sometimes of a cell. Secondly, we find *compound* bodies, measuring up to 0·04‴, or even 0·08‴, which consist of several simple bodies, surrounded by a common lamellated envelope. These structures, which were first made mention of by *Hassall* and *Virchow*, and which were further followed up by *Ecker* and *Bruch*, appear to me to arise, not by direct metamorphoses of the nuclei and cells in the walls of the lobules, but by the successive *deposition* of an amorphous substance around them, and thus to be analogous in their mode of formation to prostatic calculi. The lamellated part of these bodies consists of a substance which affords considerable resistance to alkalies, and is certainly not of a fatty nature. Its affinities are rather with colloid substance, and the substance of prostatic calculi, and it probably results from an alteration of the albumen in the gland-tissue. In certain cases, the laminated substance appears to consist of flattened cells, so that the whole bears a resemblance to the laminated epidermoid growths of pathologists. The seat of these concentric bodies is in the secretion of the thymus, but principally in the innermost parts of the walls of the gland, in the situation of the larger vessels.

§ 183. *Development of the Thymus.*—According to *Remak*, the thymus of the chick arises from the borders of the two last (third and fourth) branchial fissures, and it becomes marked off from the mucous surface lining these edges; then, following the three last aortic arches at the period when they detach themselves from the walls of the *pharynx*, the thymus comes to lie between these, as two elongated sacs.

In the earliest condition seen in mammalia (in a calf embryo, 1 inch long), the gland, according to *Bischoff*, consists of two delicate streaks of blastema, which extend downwards from the larynx towards the chest, and appear to be connected superiorly with the thyroid. *Simon* gives a similar description of the thymus in the embryoes (¾ to 1½ inch long) of the calf and pig, only he mentions nothing of a connection with the thyroid, and describes the central thread of the gland as a tube limited by a delicate structureless membrane, and filled with nuclei and a granular material. This tube, he says, becoming thicker and longer, developes itself further by sending out processes, which are at first simple, and afterwards become considerably ramified. Thus, in the embryo of the calf, ½ to 3 inches long, *Simon* found processes springing from the thymus, which were rounded and papilliform, or even furnished with short stalks. These processes increased in number by branching out in twos and fours, until at last a number of spherical bodies resulted, and these represented the lobules. On this view, the primitive tube would be converted into the central cavity of the thymus, and each outgrowth of it would become transformed into an entire lobule of the organ.—In the human embryo of the seventh week, I have observed the thymus lobulated at its inferior extremity, and simple at its superior. In an embryo ten weeks old, the superior end was a delicate-walled tube, 0·04‴ to 0·06‴ in diameter, filled with polygonal cells; and at the lower part (0·16‴ in diameter), there were separate, roundish outgrowths, of 0·02‴ to 0·03‴ in thickness, which were partly isolated, partly arranged in groups of from two to five together. The thicker and lowest part of the gland was entirely beset with lobules in a further stage of development, which measured 0·08‴ to 0·1‴, and on these, again, were seen the simple gland-granules, or acini, each having a structureless coat and a cellular interior. In the twelfth week I did not find the thymus much larger, but the whole organ had become equally beset with lobules, measuring 0·12‴ to 0·14‴. From these observations, although the first stages have not yet been seen in man, there cannot be a doubt that the gland is developed in him exactly as *Simon* has observed in mammalian animals.

The *subsequent development* of the thymus presents some other interesting conditions. In the embryo, it continues to grow slowly from the third month onwards, extends as far as the thyroid in the sixth month, and, from the seventh month onwards, contains a whitish juice. After birth it does not cease growing, as was formerly believed, but it increases very considerably soon after birth, and goes on growing up to the second year. From this period onwards it becomes no larger, but generally remains unaltered for some time longer, until at last, it wastes away and finally disappears. The period at which these final alterations take place is very various. *Simon* says that atrophy commences between the eighth and twelfth years; but my own observations, confirming those of *Ecker*, show that this statement cannot be regarded as universally true, seeing that the thymus is frequently found well nourished and distended with fluid, in the twentieth year, having experienced no metamorphosis, and having just the same structure as in children. It is still more difficult to ascertain the period of its complete disappearance, and no definite age can be assigned for the occurrence of this change, although the thymus is not, as a rule, found after the fortieth year. Its disappearance is effected by *gradual absorption of its* acini, and the simultaneous development of fat within them, fat-cells also appearing in the interlobular connective tissue. At the same time, the concentric bodies multiply more and more, and, at last, according to *Ecker*, connective tissue develops itself in the lobules, and thus the glandular structure becomes entirely effaced.

We have above traced the fœtal thymus, from its origin in a solid thread of blastema to the condition of a lobulated body with a central canal. In the organ developed thus far, some cells become changed into vessels, some into fibres; while, by the coalescence of another series, the cavities of the lobules are produced. The remainder of the embryonic cells, in the form of cells and nuclei, constitutes the special parenchyma of the gland; such a view of their origin explains why the cavities have no sharply defined walls. The nuclei in the tissue of the lobules appear to be the successors of the embryonic cells, multiplied by continual partition, so that there is no need of supposing for them any new mode of formation.—The relationship of the thymus would appear, from its microscopical character, to be principally with the lymphatic glands and allied structures; although the resemblance is not complete in details. This view, which I myself first propounded, appears so probable as to have received the sanction of *Leydig* and *Jendrassik*. If, however, the statements of *Friedleben*, a very untrustworthy observer, should be founded in truth, an affinity would appear to be shown to the spleen. At any rate, we are unable to gain a distinct clue to the functions of the organ from any anatomical considerations.

The investigation of the thymus is not easy. I especially recommend that the organ should be prepared by boiling. This is very well adapted for the investigation of the connection of the lobes with the central canals, and for the examination of the cavities in the lobules; such a preparation, when hardened in alcohol, becomes suitable for making fine sections. The fresh gland, too, may be hardened in alcohol, or pyroligneous acid, or chromic acid, or by boiling in vinegar. The thymus of small mammalia, which is membranous at the borders, is also well adapted for furnishing a general view of the part. Moreover, injections of the human thymus are absolutely necessary, for without them no satisfactory information can be obtained.

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OF THE URINARY ORGANS.

§ 184. The urinary organs consist of the two kidneys,—two true glands of a tubular structure, which prepare the urine,—and of the excretory passages, the ureters, the urinary bladder, and the urethra.

§ 185. The kidneys are composed of a secreting parenchyma, surrounded by certain envelopes. In the latter, two coats are enumerated; the one scarcely deserves the name of a special coat, for it only consists of loose connective tissue, with numerous fat-cells in its meshes: it has received the name of the *capsula adiposa*, or fat capsule. The true fibrous envelope, *tunica propria s. albuginea*, is a whitish investment, thin but firm, formed of ordinary connective tissue, and numerous fine net-works of elastic fibres. It closely envelops the kidney, and, at the hilus, becomes applied to the calyces and the vessels, without being continued into the interior of the organ, although, even at the hilus, it closely surrounds the parenchyma as far as the cortical substance extends.

Fig. 166.

A section through the middle of the kidney of a child. *a.* ureter; *b.* pelvis; *c.* calyces; *d.* papillæ; *e.* Malpighian pyramids; *f. Ferrein's* pyramid of Authors; *g.* sepra Bertini; *h.* outer part of the cortical substance.

The secreting parenchyma (fig. 166) is sharply limited by the fibrous capsule, and consists, when viewed with the naked eye, of two parts—the *medullary* and the *cortical substance.* The former of these appears in the form of from eight to fifteen isolated conical masses, with their apices towards the hilus—the *Malpighian pyramids* (fig. 166 *e*)—whilst the latter (fig. 166 *h*) forms the entire cortex of the organ, and sends inwards, between the separate pyramids, partitions which extend up to the hilus—the *Columnæ Bertini* (fig. 166 *g*). The cortical substance appears to be connected through the whole kidney without any interruption. Microscopically examined, however, the cortex is seen to divide into the same number of segments as there are pyramids present; and the kidney, accordingly, may be regarded as formed of a number of large lobes, intimately connected together.

Fig. 167.

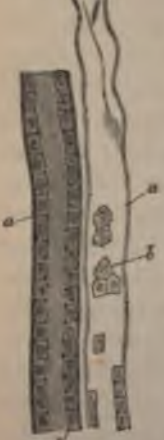
Perpendicular section through a part of a pyramid, and of the appertaining cortical substance of an injected kidney of a rabbit. Half diagrammatical figure; magnified 30 times. On the left, the vessels; on the right, the course of the urinary tubules is represented. *a.* arteriæ interlobulares with the *glomeruli Malpighiani*, *b.* and their *vasa afferentia*; *c.* *vasa efferentia*; *d.* capillaries of the cortex; *e.* *vasa efferentia* of the outermost corpuscles passing into the capillaries of the surface of the kidney; *f.* vasa efferentia of the innermost glomeruli continuing into the arteriolæ rectæ, *ggg*; *h.* capillaries of the pyramids forming from the latter; *i.* a venula recta commencing at the papilla; *k.* commencement of a straight urinary tubule at the papilla; *l.* divisions of the same; *m.* convoluted tubules in the cortex, not represented in their entire course; *n.* the same on the surface of the kidney; *o.* continuation of the same into the straight tubules of the cortex; *p.* connection of the same with the Malpighian capsules.

§ 186. *Composition of the Renal Substance.* Both portions of the kidney consist essentially of the urinary canaliculi, *tubuli uriniferi*, cylindrical tubules, measuring, on an average, 0·016‴ to 0·025‴ in diameter. They commence in every renal lobe or segment, at the renal papillæ, the part of the pyramids enclosed by the calyces. Their openings measure 0·024‴ to 0·1‴ in diameter, and are scattered to the number of from 200 to 500 upon the surface of the papillæ. Thence the tubules extend into the pyramids, in a direction mostly straight and parallel, and are hence called *tubuli recti* (or *tubuli Belliniani*) (fig. 166 *k*). During this course, each of these straight tubules repeatedly divides, mostly at acute angles, and, at first, with considerable decrease in calibre. The division is almost always into two (fig. 166 *l*), more rarely into three or four. In this manner, at last, an entire fasciculus of fine tubules arises from a single main tubule, and this explains the constantly increasing breadth of the pyramids, as they are traced from the papillæ. At the same time, the connection of the straight tubules becomes looser towards the bases of the pyramids, on account of thick bundles of vessels appearing there at regular distances (*arteriolæ* and *venulæ rectæ*), and they diverge from one another in all directions, so that, on a perpendicular section, the pyramids (the papillæ of course excepted) appear to radiate into numerous small bundles or tufts—'the pyramids of Ferrein' of some anatomists. Transverse sections, however, show that these are nowise to be regarded as definite fasciculi; though from a certain order in the arrangement of the tortuous tubules into columnar masses, there is no objection to giving the special name, pyramids of Ferrein, or, 'fasciculi corticales,' to the continuations of the indistinct bundles of straight tubules into the cortex. These are $\frac{1}{5}'''$ to $\frac{1}{6}'''$ in breadth, are distributed in the whole of the cortical portion, and as has been said, are very incompletely defined from each other. The urinary tubules, even where they leave the pyramids, have a slightly undulating course; and this is still more the case farther on in the cortical substance, where they are interwoven at first sight inextricably and without regularity, constituting the *tubuli contorti* or *corticales*. These run more straightly in the interior of a pyramid of Ferrein (fig. 167 *o*), and more crookedly at its circumference, and end in the Malpighian corpuscles, as was shown by *Bowman*, in 1842, where they come into relation with a plexus of vessels. Examined more closely, after leaving the pyramid, the tubuli uriniferi are seen to become curved laterally (fig. 167 *m*), some soon after entering the cortical portion, and more and more become so in their passage outwards. They then proceed in an undulating manner towards the arterial trunks which surround the cortical lobules, so that at last either towards the surface of the kidney (and a little distance from it), or towards the middle of the interlobular columns of *Bertini*, the whole fasciculus is broken up into tortuous tubules. The Malpighian corpuscles (fig. 167 *b*) are little bodies measuring 0·06''' to 0·1''', from which the tubuli uriniferi arise. They lie in the entire thickness of the cortex from the pyramids onwards to within $\frac{1}{50}'''$ from the surface, and they exist in the *septa Bertini* as far as the pelvis of the kidney. They are arranged so regularly and numerously around the cortical lobules, that, on every perpendicular section through the cortex, a red stripe of these corpuscles is always seen between two lobules. As a rule, such a red stripe consists of a small artery and from two to four irregular rows of corpuscles supported on it; and of these rows, some are related more to the one, others more to the other cortical bundles. Hence, *every fasciculus of uriniferous* tubules in the cortex is completely surrounded, from its commencement onwards, by Malpighian corpuscles, and, as may easily be understood, some tubules separate from the bundle earlier, others later, in order to arrive at their corpuscles. Moreover, every cortical tubule runs, after its origin, in a tortuous direction, then curves backwards; and eventually assumes a direction parallel to the straight tubules of the cortical fasciculus.

The number of the tortuous tubules corresponds to that of the Malpighian corpuscles, and is, accordingly, in every case very large. According to *Huschke*, each *fasciculus corticalis* contains 200 tubules, and each pyramid 700 such fasciculi, so that if there are 15 pyramids present, we have more than 2 millions of commencing tubules and Malpighian corpuscles. Since each papilla possesses 500 or more openings, it is possible that every cortical fasciculus arises from a single Bellinian tubule; in every case, it is observed, that on every straight tubule, the divisions are at least ten times repeated.

§ 187. The tubuli uriniferi are composed everywhere of essentially the same elements, viz., a *membrana propria* and a pavement epithelium. The former is a perfectly structureless envelope, transparent and thin (0·0004‴ to 0·0006‴), but still firm and elastic.

Fig. 168.



Two straight urinary tubules of man, the one with complete epithelium, the other half empty. *a. membrana propria*; *b.* epithelium.

It can be isolated to a very considerable extent, especially from the straight tubules, and is then apt to become disposed in folds, which often give rise to a striped appearance like connective tissue. Upon the inner side of the envelope, which quite agrees in its chemical characters with the sarcolemma (see § 77), there lies a simple layer of polygonal cells of moderate thickness around the cavity of the tubules; these are very prone to become altered, a circumstance which has given rise to many incorrect ideas of the structure and contents of the uriniferous tubules. That is to say, in the ordinary method of investigation in water, they become dilated, distended and pale from absorption of the liquid, so that their polygonal form and regular arrangement is effaced, and the renal tubules within the structureless coat appear quite filled with large roundish cells, and no longer present any cavity. Frequently, also, the cells burst, and then the tubules contain nothing but a finely-granular mass with nuclei and clear drops of albumen which has passed out of the cells. The same alterations take place spontaneously in kidneys which are not quite fresh; and it is, therefore, especially necessary to examine the organ as soon as possible after death, avoiding, at the same time, the addition of all substances which may alter its texture in any way. The contents of the epithelial cells consist of the usual round nuclei, together with a large quantity of very finely-granular matter; on the addition of water, yellowish drops, probably of albumen, readily pass out, but the cell is not otherwise altered. On the addition of acetic acid, the cell-membrane and granular contents first become pale, the cell-wall soon dissolves, and at the same time, the nucleus becomes very indistinct. Lastly, on the addition of caustic alkalies, the nucleus and cell-wall both disappear immediately. These granules I do not hesitate to regard as of a protein substance. Besides these, and the liquid albumen around them, the cells very commonly contain some small dark fat-drops, and more rarely one or two granules of yellowish pigment.

The straight and tortuous tubules present, along with the above-mentioned general characters, some minor differences. The straight tubules, although at first of considerable breadth (even 0·06‴ to 0·1‴), soon become attenuated by subdivisions to 0·01‴, 0·014‴ to 0·018″, but increase again as they leave the pyramids to 0·02‴ to 0·024‴. Of this diameter, they enter the cortex, and then increase to 0·033‴ in the proper tortuous tubules, becoming again attenuated close to the Malpighian bodies. In the tortuous tubules, the *membrana propria* is more delicate (0·0003‴ to 0·0004‴ in thickness) and more difficult to isolate; whilst, on the other hand, the epithelium is, as a rule, larger here, its cells being 0·008‴ to 0·012‴ in breadth, and 0·004‴ to 0·005‴ in thickness; whereas, in the straight tubules, the cells are only 0·004‴ to 0·006‴ broad, and 0·004‴ thick. It appears to me, also worthy of remark physiologically, that the cells of the straight tubules contain clear contents, with but few granules; and hence it happens that in an anæmic kidney the medullary substance appears whitish, while the cortex, on the other hand, is yellowish.

The Malpighian corpuscles possess a very peculiar structure; they are to be regarded as dilated appendages of the tortuous tubules, and contain, imbedded in their epithelium, a compact, roundish, vascular plexus — the *glomerulus Malpighianus*, which entirely fills their cavity. The proper coat of the tubules is continued as the envelope of these bodies (fig. 169, *a*), and here it becomes somewhat thickened, reaching 0·0005‴ to 0·0008‴ in thickness. The epithelium also passes into the capsule formed by the expansion of the proper membrane; it becomes smaller and less distinct, where it is stretched across the *glomerulus*, at the point where the vessels look towards the cavity of the efferent tube. This portion of the tubule (fig. 169, *B*) is usually more slender than elsewhere, and is attached to the Malpighian corpuscle mostly at the side opposite to the efferent and afferent vessels. As has been mentioned, its cavity is prolonged but a very little way into the Malpighian corpuscle, for the latter is almost entirely occupied by the vessels and the epithelium.

Fig. 169.

1. A human Malpighian corpuscle, *A.*, with the urinary tubule, *B. C.* arising from it. Magnified 300 times. Half-diagrammatical figure. *a.* Envelope of the Malpighian corpuscle, continuing into *b.* the *membrana propria* of the convoluted uriniferous tubules; *c.* epithelium of the Malpighian corpuscles; *d.* epithelium of the uriniferous tubule; *e.* detached epithelial cells; *f.* *vas afferens*; *g.* *vas efferens*; *h.* *glomerulus Malpighianus*. 2. Three epithelial cells, from convoluted tubules; magnified 350 times; one with fat-drops.

The ciliary movement with the direction of the current towards the ureter, discovered by *Bowman* in the frog, at the neck of the Malpighian corpuscles, and at the commencement of the tubules, can be easily confirmed when the addition of water is avoided. It is absent in birds and mammalia, but is found in serpents, in the salamander, triton, bombinator, and bufo. It is very beautifully seen in fish; and *Remak* and myself find it in the primitive kidney of the embryo of lizards, which has the structure of a true kidney; and in these two latter cases, ciliary movement is also found in the tubules, at some distance from the Malpighian corpuscles.

The question of the existence of an epithelium over the *glomerulus* is not yet finally set at rest, for very recently *Todd* and *Bowman* (*Phys. Anat.*, ii. p. 489) assert that the plexus is quite bare within the capsule. *Ecker* and others hold the same view. I may refer to my *Micros. Anat.*, ii. 2, p. 354, and only add here, that the primordial kidney and the true kidneys of amphibia and fishes, are the most suitable places for demonstrating the epithelium over the tuft of vessels.

I shall only mention here some of the very frequent pathological degenerations of the *tubuli uriniferi*. Their *membrana propria* is often thickened to 0·001‴, or even 0·002‴, and then frequently presents, on its inner side, very beautiful, delicate striæ, closely disposed in a transverse direction. The epithelial cells, especially of the cortical substance, frequently contain a considerable quantity of fat-globules, so that they then much resemble hepatic cells from a fatty liver, the more so, as they are then generally enlarged up to 0·02‴ in diameter. Along with the fat, pigment granules (of the colouring matter of urine?) also appear in the epithelial cells, both of the straight and tortuous tubules. On the other hand, the concretions of uric acid and calcareous salts, which are seen so frequently in the cavity of the canals, have not yet been demonstrated with certainty to occur within the cells themselves—at any rate, in vertebrate animals (though *Simon* ['Thymus,' p. 69] has frequently found crystals in the renal cells of fish). Bright yellow masses, resembling colloid, are very frequently met with in the epithelial cells, and these generally enlarge and develop into narrow cysts, of 0·05''' to 0·072''' in length, which at length burst and discharge their colloid contents, which are then found free in the tubules as well as in the urine. A development of the epithelial cells to other cysts, as is assumed by *J. Simon* and *Gildemeester* (*Tijdschr. d. Nederl. Maatsch.*, 1850), has not hitherto occurred to me; on the other hand, I have distinctly verified the observation of *Johnson*, and have found, in an atrophied kidney, a breaking up of the tortuous tubules into shut sacs, apparently from the development of connective tissue between them and separating them, the cysts thus formed having the same structure as the tubules, and being partly of the same width as these, and partly dilated to vesicles 0·1''' in size. *Beckmann* has recently observed the formation of such cysts in the straight tubules. The Malpighian corpuscles may also become dilated into cysts, in which, besides a clear fluid, the atrophied *glomerulus* may often be seen upon the wall. Abnormal contents may appear in the tubules as follows: 1. *blood*, most frequently in the commencement of the tortuous tubules, especially in those of the surface. This is sometimes effused in such quantities, that red points, the size of a pin's head, arise, which were formerly incorrectly regarded as dilated Malpighian corpuscles; 2. a gelatiniform substance, probably *fibrine*, in cylindrical masses, corresponding to the cavity of the tubules (see *Beckmann*, in VIRCH. *Arch.*, xi.); 3. the above-mentioned *colloid substance*; 4. concretions in the Bellinian tubules, consisting, in the adult, chiefly of carbonate and phosphate of lime; in newly-born infants, of uric acid salts, which give the pyramids a bright golden-yellow colour. Though not without exceptions, still it is the rule that these crystals only occur in children which have breathed (between the third and twentieth day). In the later stages of '*Bright's* disease,' many tubules, which have lost their epithelium by exudation into them, become atrophied, and ultimately completely disappear, whilst groups of others become filled with fatty disintegrating exudation, and are dilated so as to form small prominences—the 'granulations' of *Christison*.

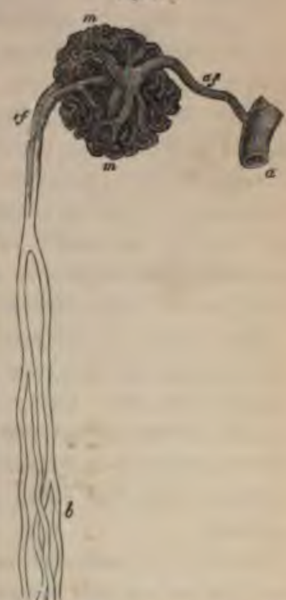
§ 188. *Vessels and Nerves.*—The large renal artery divides, in the pelvis of the kidney, into a certain number of branches, which supply the parts situated in the hilus, and then pass above and beneath the renal nerves into the cortical substance—the *columnæ Bertini*—situated beneath the pyramids. From hence they run close to the line of demarcation between the pyramids and cortical substance, and divide repeatedly, so as to form a beautiful ramification without anastomoses, generally from two large arteries. From the part of this branch-work which is directed towards the cortical substance, small arteries arise at right angles with great regularity, and these divide several times, until they form fine branches (0·06‴ to 0·1‴), which run directly outwards between the cortical fasciculi, and may be most fitly called *arteriæ interlobulares* (fig. 167, *a*). It is these which support the Malpighian corpuscles, and, apart from some twigs which pass to the envelope of the organ, are entirely consumed in the formation of their vascular coils. That is to say, each interlobular artery gives off, in its entire length, and in two, three, or four directions, a large number of fine twigs of arterial structure, with a diameter of 0·008‴ to 0·02‴; and these, after a short course, penetrate the envelope of a Malpighian corpuscle, either directly or in several divisions, and appear as the *vasa afferentia* of its vascular coil. Each of these vascular coils (figs. 169, 170) consists of a dense convolution of fine vessels, of 0·004‴ to 0·008‴ in diameter, having the ordinary structure of capillaries (with structureless wall and nuclei), and are provided with an efferent vessel besides the entering artery. The manner in which these two vessels are connected with each other is not that which occurs between arteries and veins, but resembles that which is found in the so-called *rete mirabile*, the vas afferens dividing, immediately after its entrance, into five to eight branches, and each of these, again, into a tuft of capillaries. These are twisted and wound together in various ways, and pursue their course without forming anastomoses. They at last re-unite to form a trunk, in exactly the same manner as they themselves were formed. As a rule, the two trunks of the glomerulus enter and pass out near to each other, and opposite the origin of the tubule; the finest vessels of the coil (0·003‴ to 0·004‴ in diameter) are invariably found exactly at the spot where the urinary tubule commences. In birds, amphibia, and fish, each glomerulus consists of one single tortuous vessel.

Fig. 170.

From the human kidney, after *Bowman*. *a*. Termination of an *art. interlobularis*; *b*. *arterial afferentes*; *c*. naked glomerulus; *d*. *vas efferens*; *e*. glomeruli enveloped by the Malpighian capsules; *f*. uriniferous tubules arising from the same. Magnified 45 times.

The *vasa efferentia*, although arising from capillaries, are still not veins, but have the signification, and, in part, the structure, of small arteries. These, in their further course, break up into the capillary network of the kidney, both in the cortex and pyramids, presenting a somewhat different character at the two places. In the cortex (fig. 167, *d*), the *vasa efferentia*, 0·004‴ to 0·008‴ in thickness, break up, after a short course, into a very close network of capillaries (0·002‴, 0·004‴ to 0·006‴ in diameter, with roundish, angular meshes, 0·005‴ to 0·015‴ wide), which surrounds the tortuous tubules on all sides, and may be regarded as continuous throughout the whole cortical substance. It is only the efferent vessels of those glomeruli which border immediately upon the Malpighian pyramids which form an exception to this condition. These are not distributed to the cortex, but to the pyramid; they are uniformly characterised by their more considerable diameter (0·01‴ to 0·016‴), their extended course, and the scanty amount of their ramification. These, which, with *Arnold*, I will call *arteriolæ rectæ*, penetrate into the whole circumference of the pyramids, directly between the Bellinian tubules, run downwards towards the papillæ, at the same time dividing repeatedly at acute angles, and gradually become attenuated to 0·004‴ to 0·01‴ in diameter. At last, these straight arteries pass into capillaries (0·003‴ to 0·004‴), both in the papillæ and in the interior of the pyramids. These capillaries are continuous with those of the cortex at the margin of the pyramids, but are distinguished from them by their smaller numbers and the elongated form of their meshes. The *renal veins* commence at two places, viz., at the surface of the organ and at the apices of the papillæ. The former are the veins of the cortex, and begin by small venous radicles, collecting the blood from the outermost portion of the capillary network. These small veins surround each separate *cortical fasciculus* in a regular manner, and unite in a stellate

Fig. 171.



Glomerulus, from the innermost part of the cortex of the kidney of the horse, after *Bowman*. *a*. *art. interlobularis*; *af*. vas afferens; *m m*. glomerulus; *ef*. *vas efferens sive arteriola recta*; *b*. division of the same in the medullary substance. Magnified 70 times.

fashion into larger roots (*stellulæ Verheynii*); while others of the veins, extending over several of the lobules, also join each other to form larger vessels. In whichever way formed, these larger veins pass inwards as the *venæ interlobulares*, and are continued, between the cortical fasciculi, along with the arteries of the same name. Here they are reinforced by the reception of numerous other venous radicles from the interior of the cortex, and pass over into the larger veins at right angles. The larger veins lie with their arteries at the circumference of the pyramids, and end, at last, in the main veins. These, like all renal veins, are destitute of valves; they are of the same number as the arteries, and leave the kidney like these. Before leaving the organ, however, these veins receive additions from the *columnæ Bertini*, and are joined by the second set of renal veins, those from the pyramids. These commence with a beautiful network, surrounding the apertures of the urinary tubules on the papillæ, become reinforced by other radicles as they ascend between the *tubuli recti*, and are placed by the side of the arteries of the pyramids — the vasa efferentia of the innermost glomeruli, or the arteriolæ rectæ. Thus large vascular bundles are formed, especially around the fasciculi, at the bases of the pyramids, which open, in an arcuate manner, into the dense venous ramification which surrounds the pyramids.

The *vessels of the renal envelopes* arise partly from the renal artery before its entrance into the hilus, and from the capsular and lumbar arteries. Other fine twigs are furnished to the fibrous capsule from the arteriæ interlobulares, after they have supplied the Malpighian corpuscles; a capillary network results with wide meshes, which has connexions with vessels in the so-called 'tunica adiposa.'

The kidney possesses relatively few *lymphatics*; they run in the interior, along the larger vessels, and do not appear to extend beyond the *vasa interlobularia*. In the hilus, they unite to form some trunklets, which receive lymphatics from the pelvis of the kidney, and then open into the lumbar glands. I have not hitherto seen superficial lymphatics, such as are described by the older anatomists (*Nuck*, *Cruikshank*, *Mascagni*, and others), except in the fat-capsule, although I do not mean to deny their existence in the fibrous envelope.

The *renal nerves*, from the cœliac plexus of the sympathetic, are tolerably numerous; they form a plexus surrounding the arteries, possess some ganglia in the hilus, and can be followed with the vessels as far as the interlobular arteries. Where and how they terminate is unknown.

All the vessels and nerves are supported by areolar tissue, which serves, at the same time, as a stroma for the secretory structures, and is much more developed in the pyramidal than in the cortical substance. On the surface of the kidney, it frequently becomes condensed, and forms a very distinct membrane, of 0·01‴ to 0·02‴ in thickness, which is only loosely connected with the fibrous capsule; here it assists in supporting the superficial capillary network, and is connected with the internal stroma by numerous delicate processes.

Fig. 172.

Transverse section through some straight tubules of the cortex of the human kidney; magnified 350 times. *a*. Transverse sections of urinary tubules, of which the *membrana propria* is alone preserved; *b*. the same, where the epithelium is still present; *c*. stroma of areolar tissue, with elongated nuclei; *d*. space, which has contained a Malpighian corpuscle.

Virchow has lately put forth some views on the distribution of the renal vessels, which differ from those usually received — those of *Arnold* excepted. While *Virchow* admits that the arteries of the pyramids, or their capillaries, are prolonged from the efferent vessels of the Malpighian bodies, he also maintains that the arteriolæ rectæ have no such origin, but are derived directly from the renal arteries, especially from those branches which bear the Malpighian coils. Now, neither in the lower mammalia nor in man, can it be doubted that all the glomeruli on the margins of the pyramids give their efferent vessels as true arteriolæ rectæ; but I am not prepared wholly to deny *Virchow's* position without a re-examination of the question. Possibly it may be true, that in man some of the arteries of the pyramids are given off direct from the renal arteries, although, in the amphibia, and other lower animals, there is no question that the whole blood of the kidney does pass through the glomeruli. The fact, well known to anatomists, that in common injections of whole bodies the vascular coils often are injected, while the pyramids are quite free, argues little for any direct passage of arterial blood into the pyramids. It may be remarked, too, that *Virchow* gives the diameter of these arteriolæ in question as three times greater than has been stated above, even up to 0·03‴ to 0·04‴.

In inflammation and exudations into the kidney, the stroma frequently becomes thickened so considerably, that it is apparent on the most superficial observation, and even more or less displaces the urinary tubules. The parts newly added to it consist chiefly of a fibrinous exudation, in different stages of transition into areolar tissue, partly, also, of forms which belong to areolar tissue in process of normal formation, such as plastic cells. These new formations often appear in the interior of the Malpighian corpuscles (*Frerichs*), usually in the form of concentric depositions, frequently very thick, which compress the afferent and efferent vessels, and thus produce atrophy of the glomerulus, so that the secretion of urine becomes very materially impaired.

In other cases, the increase of the stroma is more apparent than real, being occasioned by the disappearance of the secreting parts. In chronic diseases of the kidneys, the walls of the arteries, and of the vessels of the glomeruli, are frequently thickened and impregnated with depositions of fat (*Johnson*).

§ 189. *Excretory Urinary Passages.*—The ureter, the pelvis, and calyces of the kidney all consist of an outer fibrous coat, a layer of smooth muscular fibres, and a mucous membrane. The *outer* coat, formed of ordinary connective tissue and elastic fibres, chiefly of the finer sorts, passes into the fibrous capsule of the kidney at the parts where the calyces embrace the papillæ. The *muscular layer* is very distinct in the ureters, and here presents external longitudinal, and internal transverse fibres, to which, in the neighbourhood of the bladder, other longitudinal fibres are added internally. In the pelvis of the kidney, the two muscular laminæ are just as thick as in the ureter; but they become thinner and thinner in the calyces, and terminate where these are attached to the papillæ. The *mucous membrane* of all these parts is thin, tolerably vascular, without glands or papillæ, and is continued, very much attenuated (0·005‴ to 0·01‴ in diameter without epithelium), upon the papillæ of the kidney, where it becomes connected with the internal stroma of the organ. The epithelium, covering this mucous membrane, is 0·02‴ to 0·04‴ in thickness, and is in several layers. It is remarkable for the varying form and size of its elements, which are small and roundish cells in the deep portions, cylindrical or conical (0·01‴ to 0·02‴ in length) in the middle; while at the surface, the epithelium consists of roundish, polygonal cells, 0·006‴ to 0·04‴ in size, or of flattened plates, measuring up to 0·02‴. A peculiarity in these cells is the frequent occurrence of two nuclei in their interior, and clear round granules, with a

Fig. 173.

Epithelium of the pelvis of the kidney, of man; magnified 350 times. *A.* Isolated cells; *B.* the same *in situ*. *a.* small, *b.* large pavement cells; *c.* the same with nucleus-like bodies in the interior; *d.* cylindrical and conical cells from the deeper layers; *e.* transition forms.

darkish contour, are also found; these vary from 0·001‴ to 0·002‴ in size, and have often very much the appearance of nuclei themselves.

The urinary bladder is composed of layers similar to those of the ureter, and receives, in addition, a covering from the peritonæum. The muscular coat is made up of an external longitudinal layer, which is well known under the name of *detrusor urinæ*. This layer is composed of parallel fasciculi, which are provided with elastic tendons here and there (*Treitz*), and single fibres are continued from these bundles upon the urachus. The next layer of the muscular coat consists of a meshwork of fasciculi of variable size, running obliquely and transversely, and matted together; at the neck of the bladder, these pass into a continuous layer of circular fibres, the *sphincter vesicæ*. A thick stratum of yellowish-white fibres, situated immediately under the mucous membrane of the fundus of the bladder, has received the name *corpus trigonum*, and to this the so-called *uvula vesicæ* (*valv. vesico-urethralis*, *Amussat*), at the orifice of the urethra, is attached. This *corpus trigonum* is connected with the longitudinal muscular fibres of the ureters as they pass through the muscular coat of the bladder; and it is composed of connective tissue, smooth muscular fibres, and fine elastic elements; these last are mostly longitudinal, but partly transverse in direction. *V. Ellis* calls this stratum of fibres the submucous muscular stratum of the bladder, and states that it extends upwards for some distance above the trigonum. The mucous membrane of the bladder is pale, smooth, and rather thick, with abundant submucous tissue everywhere but at the trigonum; this allows the mucous coat to fall into numerous folds in the contracted state of the organ. The membrane is destitute of villi; it is well supplied with vessels, especially at the fundus and neck. The nerves of the mucous membrane are not very abundant, except at the base and cervix; they are dark-bordered fibres, fine and of medium thickness.—The epithelium of the bladder measures from 0·03‴ to 0·05‴ in thickness, and is formed of cells arranged in laminæ. The deeper cells are spindle-shaped, conical, or cylindrical, while the more superficial are roundish, polygonal, or flattened. In the irregularity of their shape they rival the cells of the pelvic epithelium; the more superficial cells are frequently indented, to receive the ends of the elongated ones below them, and peculiar stellate and toothed shapes are thus produced. In the neck and fundus of the bladder small glands are met with, either in the form of simple pyriform tubes, or of simple racemose glandules from the aggregation of such. These glands measure 0·04‴ to 0·24‴, and have apertures of 0·02‴ to 0·05‴ in diameter; they contain a cylindrical epithelium and a clear mucus. In pathological cases, *Virchow* finds them to be here and there enlarged, and filled with whitish plugs of mucus.

The male urethra will be considered when treating of the sexual organs. That of the female is made up of a *mucous membrane* and a muscular layer; the former is of a red colour, being provided with numerous vessels, especially with well-marked venous networks in the submucous tissue (*Kobelt*, without reason, has described these as a *corpus spongiosum*). It has a laminated pavement-epithelium, consisting of elongated cells in the deeper portion, as in the bladder. The muscular fibres of the female urethra are arranged, on the one hand, into thin layers running longitudinally and transversely, in connection with the mucous membrane, and intermingled with much connective tissue and elastic fibres; on the other hand, they form the thick *musculus urethralis*, whose fibres run chiefly in the transverse direction. These fibres are all of the plain variety. A certain number of racemose mucous glandules (Littre's glands), the same in structure as those of the bladder, only mostly larger and more compound, pour their secretion into the urethra. Occasionally, they are found enlarged up to 2 lines in size, their mucous membrane swollen and protruded, and their enlarged tubes filled with a colloid substance, or even with concretions resembling prostatic calculi.

§ 190. *Physiological Remarks. Development of the Urinary Organs.*—In the chick, according to *Remak*, the kidneys are formed as two hollow processes from the rectum, in which the epithelial and fibrous laminæ of the latter are concerned. Their further growth, like that of the lungs, is by the ramification of their epithelial tubes, and by the increase in size of the fibrous lamina (*Investigations into the Development of Vertebrata*, tab. ii., fig. 83—85). In mammalia, the first development of the kidney has not yet been observed; on the other hand, the subsequent changes, as we learn them from the researches of *Rathke*, *J. Müller*, *Valentin*, and *Bischoff*, agree very well with the statements of *Remak*, only that in the mammalia the tubules appear to be solid at the beginning, and to be developed after the type of the salivary glands. In mammalia, the kidneys consist of nothing else, at their first formation, than the pelvis and a certain number of club-shaped cavities connected with it, and representing the calyces. From each of these cavities tufts of urinary tubules are next formed by the continued formation of processes, and each of these tufts is ultimately transformed into a Malpighian pyramid, with its appertaining cortical substance; the kidney, at the same time, grows into a corresponding number of large lobes. The urinary tubules are at first solid, composed only of cells, straight, and without a *membrana propria*. In the course of development, this latter membrane makes its appearance, probably from a plasma secreted by the cells, and the cavities of the tubules become developed, probably from the collection of a fluid between the cells; at the same time, the tubules begin to grow quickly in length, and to become tortuous. The Malpighian corpuscles are originally nothing but solid, clavate, thickened terminations of the rudiments of the tubules. At a later period, the inner cells of these pyriform or roundish bodies are converted into capillaries, which are connected at two places with the external vessels; whilst the more external are transformed into an epithelium, which becomes continuous with that of the urinary tubules, and becomes surrounded, in like manner, with a *membrana propria*. This membrane is, of course, wanting at the parts where the vessels enter and pass out. According to *Harting*, the tubules are three times narrower in the newly-born infant than in the adult, and, as the kidney of the latter is only double the size of that of the child, it is evident from this that no tubules are developed subsequently to birth.

On the physiology of the kidney, I shall only make the following remarks. It cannot be called in question, that the peculiar arrangements of the vessels in the kidney, the flow of blood through coils projecting into the commencement of the urinary tubules, before it passes into the proper capillary network of the organ, is most intimately connected with the excretion of large quantities of water by the urine. Through the impediments to the flow of the blood in the glomeruli, a considerable lateral pressure is produced, and a large quantity of blood-plasma must be forced through the thin opposing membrane, that is, through the coat of the capillaries and the epithelium. But as all the constituents of the plasma are not found in urine, and as those which are present are found in very different proportions in the urine and in the blood, it is obvious that the membrane in question does not act simply like a filter, but, by means still unknown to us, retains certain matters, and allows others to pass through with great facility. Of the former kind of substances, protein matters and fat, of the latter kind, urea, afford the most obvious instances. Thus there appears to arise in the commencements of the tubules a very diluted urine, which then, during its passage towards the pelvis of the kidney, enters into mutual relation with the blood bathing the tubules, takes up from it new materials, (probably more urea), and gives off, at the same time, certain of its constituents, such as water and salts. Thus it becomes, for the first time, *urine*, in the proper sense of the word.

We know very little about the chemical composition of the kidneys. *Frerichs* (l.c. p.42) found in a healthy kidney 16·3 to 18 per cent. of solid parts (*Lang* 18·1 to 20 per cent.), with 72 to 73·7 parts of water. Of the solid portion, the fat amounted to 0·63 to 1·0 per cent., still, according to *O. Rees*, it may increase to 1·86 (*Lang* finds 2·0 to 2·8 per cent. fat; in one case, the medulla contained 1·7, the cortex, 2·4). The greater part, however, appears to be albumen, *Ludwig*, more especially, having shown that it exists in large quantities in the kidney; and this cannot be surprising, when we consider the micro-chemical condition of the epithelial cells of the urinary tubules.

An important addition has lately been made to our knowledge of the chemistry of the kidneys, in the discovery by *Cloetta* of inosite, hypoxanthin (or xanthin), cystin and taurin, in the substance of the organ. *Beckmann* has also established the existence of leucin and tyrosin. The occurrence of these substances renders it very probable, as *Beckmann* has pointed out, that certain constituents of the urine are real products of the kidney, and are not merely separated by this organ from the blood.

The secretion of the urine takes place in the higher animals without the formation and solution of cells; and, accordingly, the normal newly secreted urine contains no morphological elements, with the exception of a few fat-drops (*Lang*). It is only accidentally that we find *epithelial cells* in it, and these are derived from the excretory passages, especially the bladder and urethra; but mucus from the same localities is almost always present, as a slight turbidity or sediment occasionally containing mucous corpuscles: spermatozoa, too, may be found, after evacuation of semen. In inflammations, hemorrhages, exudations, and formation of fat in the kidneys, the urine contains pus corpuscles, fat-globules, blood-discs, or coagula of blood and fibrine. These are aggregated into cylindrical plugs, which are casts of the urinary tubules; and besides these, we meet with epithelium of urinary tubules, either isolated or arranged in connected strings or tubes. *Sediments* of the salts of the urine are very readily formed in consequence of decomposition. Normal urine without sediment, exposed for a while to a moderate temperature, always passes into an acid fermentation by the action of the contained mucus. Along with the fungi thus produced, the colouring matter of the urine undergoes decomposition into lactic and acetic acids; and by this means the uric acid is freed from its combinations, and is precipitated in the form of rhombic or prismatic crystals, coloured yellow or reddish by the colouring matter of the urine. The acid disappears earlier or later, the urine becomes ammoniacal and alkaline by the decomposition of the urea, and, perhaps, also of the colouring matter, and large colourless pyramidal prisms or stellately disposed needles of ammoniaco-magnesian phosphate, soluble in acetic acid (triple-phosphate), make their appearance; these, mingled with numerous infusoria (vibrions and monads), form a superficial pellicle and a white sediment, in which the crystals of triple-phosphate are mixed with granules of urate of ammonia, and, perhaps, also of carbonate of lime. Under exceptional circumstances, which we do not yet understand, there appear in the urine the six-sided prisms of *cystine*, but a more frequent deposit is composed of oxalate of lime, in the form of octohedra insoluble in acetic acid: these occur especially after the use of aërated drinks, and also in pregnant women. The *uric acid* becomes increased, after the use of highly azotised food, after disturbance of the digestion, by want of exercise, in fevers, etc., and then there forms, on the cooling of the urine, a yellowish sediment, more or less abundant, of *urate of soda*, in the form of granules, isolated or collected in heaps, and dissolving when the urine is heated. If now the acid fermentation begin, the most abundant sediments of coloured crystals of uric acid (brick-red sediments) are often thrown down. In affections of the bladder, the urine often becomes quickly alkaline, and then the above-mentioned crystals of triple-phosphate immediately present themselves. The latter are also very frequently observed in pregnant females, and in the form of the above-mentioned pellicle, were at first held to be a peculiar substance (*Kiesthein*).

The occurrence of albumen, fibrine, and fat, in the interior of the urinary tubules, can, in my opinion, be easily explained, on the assumption that in these cases a disturbance of the circulation takes place with an increased transudation of the constituents of the blood into the Malpighian corpuscles and the urinary tubules; and that, in consequence of this exudation, the epithelium of these parts becomes detached. This would account for the well-known fact, that, in these cases, epithelium appears in the urine in large quantities; and we may be sure, that after such separation of the epithelial cells, there would be no further hindrance to the passage of the albumen and fibrine. It is, indeed, conceivable, that the fibrine should escape by penetrating the epithelium, as we know may occur in the instance of the respiratory mucous membrane; but I do not believe that an amount of pressure sufficient to produce a transudation of fibrine, would leave the delicate epithelium uninjured. When once the epithelium is wanting, it is very questionable whether it is quickly reproduced; and it appears to me, that the frequent occurrence of small quantities of albumen in the urine may often be dependent upon nothing else than a local absence of the epithelium.

Investigation of the Kidneys.—The urinary tubules can be readily isolated by teasing them out, and the epithelium, *membrana propria*, and cavity become distinctly recognisable when moistened with the serum of blood or a solution of albumen. Along with entire tubules, there are found, in every preparation, numerous epithelial cells, isolated and in heaps, or even forming *continuous long tubes: these latter* are met with chiefly in the pyramids, and often present a peculiar appearance, exhibiting collapsed flattened cells, and thus resembling vessels. With equal frequency, we also meet with shorter or longer tubes of the *membrana propria*, which, when they are folded, are not always immediately recognisable. In examining the pyramids, the very numerous vessels are not to be confounded with the Bellinian tubes or their detached epithelium. The connection of the tubules with the Malpighian capsules can be readily found in the kidney of the frog and fish, on carefully teasing them out; but, even in mammalia, they will be seldom sought for in vain, when fine sections are examined after being hardened, and more especially when injected preparations are used. The glomeruli themselves may be frequently recognised in their natural condition, but still better after injection. This may be easily done from the arteries with any kind of fine size, and if such an injection is successful, the whole capillary net-work of the cortex and pyramids is also filled; and then this part of the circulatory apparatus can be very satisfactorily observed on a perpendicular section. It is also well to examine kidneys injected from the veins, in which only the capillary net-work, but not the glomeruli, are filled; and for the study of the *vasa efferentia* from the arteries, preparations not completely filled with injection are to be used. The course of the urinary tubules is to be studied on fine sections of kidneys, hardened first in alcohol, then by boiling in diluted nitric acid and drying (*Wittich*), on kidneys hardened in chromic acid, and afterwards rendered clear by acetic acid: or the tubules may be studied on sections made by the double knife on fresh or injected kidneys; and on these sections we may recognise the important fact of the division of Bellinian tubules. Still it is always useful to inject the uriniferous tubes, and for this object the kidney of the horse is better adapted than that of any other mammalian. Such an injection may be produced accidentally by extravasation into the Malpighian capsules in the process of injecting the arteries; but then, however, seldom more than the tortuous tubules are filled. It is better to inject them from the ureter with the aid of the air-pump (HUSCHKE, *Isis*, 1826); or whilst the pelvis of the kidney is kept constantly filled, the size may be forced into the straight tubules, and beyond these into the tubules of the cortex, by kneading the calyces with the hand (*Cayla*). The individual tubules may also be injected directly from the papilla by means of very fine canulæ.

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OF THE SUPRARENAL CAPSULES.

§ 191. The *suprarenal capsules, glandulæ suprarenales*, are double organs, which in structure are most nearly allied to the vascular glands. Their function is entirely unknown. Each suprarenal capsule possesses a pretty firm but thin investment of connective tissue, which surrounds the whole organ, and is connected by numerous processes with the proper *parenchyma*. This is composed of a cortical and medullary substance. The former, *subst. corticalis*, is rather dense, $\frac{1}{8}'''$ to $\frac{1}{2}'''$ thick, tearing slightly in the direction of the thickness, and presenting, when torn, a fibrous appearance. Its colour is for the most part whitish-yellow or yellow, usually passing, however, in the innermost third, into brownish-yellow or brown, so that we distinguish upon section two layers, an exterior, broad, lighter layer, and an interior narrow, dark edge. The *medullary substance* is, in its normal condition paler than the cortex, being greyish-white with a reddish tinge; still, when its numerous veins are filled with blood, it may assume a darker and more venous colour. Its consistence is less than that of the cortex, yet not so very much so as is usually believed. In amount it is very inconsiderable, being no more than $\frac{1}{6}'''$ to $\frac{1}{3}'''$ thick at the borders and at the superior external extremity of the organ, increasing to $1'''$ or even $1\frac{1}{2}'''$ in the middle and at the inferior internal half. In man, the cortical substance separates in the dead body extremely readily from the medullary substance, and the suprarenal capsule then contains a cavity which may occupy the entire organ. In this cavity there is contained a dirty grumous material mingled with blood, and coming from the half-disintegrated brown layer of the cortex. Along with this, unaltered medulla is also found, but this, too, in rarer cases, is likewise broken down.

§ 192. *Intimate Structure.*—The cortical substance consists of a framework of delicate interlacing fibres of connective tissue, which are connected with, and proceed from, the envelope, and traverse the cortical substance in the form of thin laminæ, united with each other. These laminæ constitute the walls of little compartments, which are in a very large number and closely arranged, measuring 0·016‴ to 0·02‴ or even 0·03‴ in breadth, and running perpendicularly from without inwards, through the whole thickness of the cortex. In these compartments lies a granular material, which is divided by delicate dissepiments of connective tissue, running obliquely or transversely into larger and smaller groups. These are described by *Ecker* as *gland-tubes*, and as containing within a structureless coat a granular material intermingled with nuclei and cells. I prefer to give these elements merely the name of *cortical cylinders*, as in most of them I have seen nothing else than roundish angular cells of 0·006‴ to 0·012‴ in diameter; and I believe that *Ecker* has been induced by the rare occurrence of true tubes (whose significance I shall immediately discuss), to regard the compact aggregation of the above-mentioned cells occurring in the interior of the cortex also in the light of special tubes. The truth appears to be, that the cells are more isolated in those compartments which adjoin the inner or the outer surface of the cortex; while in the compartments of the interior of the cortex, the cells are firmly united in the form of oval or cylindrical masses (0·024‴ to 0·048‴ in length), in which the outlines of the cells frequently coalesce into a single general contour. I have, however, never succeeded in finding any other envelope enclosing the cells than the connective tissue, which is met with in the other compartments, and I almost always have succeeded, by pressure or the addition of alkalies, in isolating the cells, without any special tube coming into view. Hitherto, I have observed *true* tubes only in the internal parts of the cortex, as round or oval vesicles, 0·02‴ to 0·03‴ in size, in the interior of which no cells, such as form the cortical cylinders, were to be recognised, but only an aggregation of fat globules, and these tubes I am inclined to consider as enlarged cells. The contents of the cells of the cortex consist

Fig. 174.

A piece of a perpendicular section through the cortex of the human suprarenal capsule. *a*, partitions of connective tissue; *b*, cortical cylinder, whose cellular composition is more or less distinct; mag. 300 times.

normally of fine granules of a nitrogenous substance; to which, however, there are almost always added separate fat-granules, and these, in many cases (when the cortical substance is yellow), are present in such numbers that they completely fill the cells, which then closely resemble the hepatic cells of a fatty liver. In the brown layer of the cortex, the cells are completely filled with brown pigment granules.

Fig. 175.

From the suprarenal capsule of man. *a.* five cells filled with pale contents from the apex of a cortical cylinder; *b.* pigment-cells from the innermost lamina of the cortex; *c.* fatty cells, from a yellow cortical lamina; *d.* a large cyst filled with fat from such a cortex (gland-tube, *Ecker*); *e.* cells from the medullary substance, some with processes. Magnified 350 diameters.

The medullary substance has likewise its stroma of connective tissue, which, as a continuation of the cortical laminæ, traverses the whole interior with delicate bundles, and presents a net-work of tolerably close, roundish meshes. In these meshes lies a pale finely granular substance, in which in man, I have almost always observed on careful treatment, and in fresh preparations, pale cells, 0·008''' to 0.016''' in diameter. The contents of these cells are finely granular, sometimes with a little fat or some pigment granules; the cell-nuclei are frequently very beautiful, and have large nucleoli. The form of the cells is angular, and they occasionally exhibit processes from their sides, one or more in number, and sometimes branching. All these circumstances give these cells a strong resemblance to the nerve-cells of the nervous centres, though the two cannot with certainty be regarded as identical.

§ 193. *Vessels and Nerves.*—The blood-vessels of the suprarenal capsules are numerous; they lie in the stroma of connective tissue, and form two kinds of capillary net-works — the one in the cortex with elongated meshes, the other in the medulla with roundish interspaces. The arteries arise as numerous small trunks from the neighbouring larger arteries (from the phrenic, cœliac and renal vessels, and from the aorta); they frequently number as many as twenty, and are distributed in part by penetrating directly into the medulla, partly by ramifying in the cortex. The latter vessels are more numerous and much ramified; they cover the outer *surface of the organ,* and form a fine capillary net-work, even before they leave the envelope. Then, breaking up into numerous fine twigs, they dip into the septa of connective tissue in the cortex, and run in these directly towards the medulla. In their course they become smaller and smaller, and are connected together by numerous transverse anastomoses, so that the cortical cylinders are surrounded by blood on all sides. The extremities of these vessels extend into the medulla, and form in it a dense capillary net-work of somewhat larger vessels, by anastomosing with the arteries which pass into it directly (some of which, however, in the sheep, according to *Nagel*, pass quite out of the medulla back into the cortex). The veins arise chiefly from the latter capillary net-work, and unite within the medullary substance to form the principal vein of the organ—the *vena suprarenalis*—which passes out at the anterior surface from the so-called *hilus*, and opens on the right side into the vena cava, and on the left, into the renal vein. A considerable number of small veins also pass out of the cortex, and these partly accompany the arteries in pairs, and open into the renal and phrenic veins, and into the vena cava. As for lymphatic vessels, I have hitherto only seen some trunklets on the surface of the organ, but none in the interior or coming from it.—The nerves of the suprarenal capsules, as *Bergmann* correctly stated, are extremely numerous, and come from the semilunar ganglion and the renal plexus; according to *Bergmann*, a small part comes also from the vagus and phrenic. In man, I counted thirty-three nervous trunks on the right suprarenal capsule, eight having a diameter of $\frac{1}{5}'''$ to $\frac{1}{10}'''$; five, from $\frac{1}{14}'''$ to $\frac{1}{20}'''$; seven measuring $\frac{1}{25}'''$ to $\frac{1}{33}'''$; and thirteen, $\frac{1}{45}'''$ to $\frac{1}{50}'''$ in diameter; and found them to consist almost without exception of dark bordered nerve-tubes, fine and of medium thickness; some, however, actually of the thicker kind. In colour they were whitish or white, and were studded with separate ganglia of various size. The nerves pass to the organ, especially at the lower half and at the internal border, and all appear to be destined for the medullary substance; here we always find (at least in the lower mam-

Fig. 176.

Transverse section of the suprarenal capsule of the calf, magnified about 15 times, and treated with caustic soda. *a*. cortex; *b*. medulla; *c*. central vein surrounded by some cortical substance; *d*. three entering nervous trunks; *e*. nerves, and their distribution in the interior.

malia), an extremely rich net-work of dark-bordered, fine tubes enclosed in the trabeculæ of connective tissue, although their terminations are nowhere perceptible. In man, the medulla is so altered, that the nerves can be traced only to their entrance into it, and their further distribution it has not hitherto been possible to ascertain.

§ 194. *Physiological Remarks.*—The suprarenal capsules are developed contemporaneously with the kidneys, and independently of them, from a blastema, which arises from the middle germinal lamina (*Remak*), and about the first appearance and growth of which nothing is known. These organs are, at first, larger than the kidneys; but in the third month, they are equal to the kidneys in size; in the embryo of six months, the weight of the suprarenal capsules is to the kidneys as 2 to 5; in the mature fœtus, as 1 to 3; in the adult, as 1 to 8 (*Meckel*). In the lower mammalia, the suprarenal capsules are from the commencement onwards smaller than the kidneys, and grow in the same ratio as the latter. Very little is known concerning the histological development of the organ. I have investigated it hitherto only in an embryo of three months, where, like *Ecker*, I found the cortex whitish, the medulla reddish-white, and both consisting of cells and fibres. The cells measured 0·012‴ to 0·02‴ in diameter; they had beautiful, in part colossal, nuclei, with splendid nucleoli, as well as fat molecules in the cells of the cortex. I have not yet seen anything of the development of the nerves. *Ecker* saw nothing of the tubes in a newly-born rabbit, but found them very distinct in a calf embryo, 1½ feet in length; but they were small, measuring only 0·05 to 0·15 of a millimetre.

In the absence of all physiological data, and in our ignorance of the exact distribution of the nerves within the organ, any remarks on the functions of the suprarenal capsules must at present be of the most general nature. I will only remark, that I regard the cortical and medullary substances as being physiologically different. The former may, for the present, be classed with the so-called vascular glands, and some relation to secretion may be ascribed to it; whilst the latter, on account of its unusual richness in nerves, must be considered as an apparatus belonging to the nervous system, in which the cellular elements and the nervous plexuses either influence each other in a similar manner as in the gray nervous substance, or are related to each other in some other way not yet ascertained (see my *Micr. Anat.* II., 2, p. 384). It is probable, that a more accurate chemical examination of the organ might furnish more precise conclusions. Already we learn from *Vulpian* of a substance obtained from the cortical substance, which has a beautiful rose colour in its watery solution, and turns green on the addition of the persalts of iron. According to this author, hippuric and taurocholic acids also are to be found; and *Virchow*, besides confirming these statements, has established the presence of leucin and lecithin (myelin *Virch.*) in large quantities.

For the *investigation* of the suprarenal capsules, those of the larger mammalian animals should first be chosen, and then those of man. The cortex is easy to investigate when its elements contain little fat; and fine perpendicular sections of the body may be studied either in the fresh organ, or in one that has been hardened in alcohol and chromic acid, and rendered clear by acetic acid. The medullary substance breaks down very readily even in animals, so that its elements are not at all, or are only partially visible in their normal condition, still they may occasionally be very beautifully seen without further trouble in the recent organs, as well as in chromic acid preparations. The nerves are extremely easily found on fine sections of the capsule in animals, after the addition of caustic soda; and when the section is made exactly at their place of entrance, their passage through the cortex can be readily brought into view. In order to examine the vessels, injections must be made (best in the sheep or sucking pig), which readily succeed, both from the arteries and the veins, as these latter are not furnished with valves.

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OF THE SEXUAL ORGANS.

A. Male Sexual Organs.

§ 195. The *male sexual organs* consist, 1, of the testicles, two glands for the secretion of the semen, which, with their special envelopes, the *tunicæ vaginales*, are contained in the scrotum; 2, of the excretory ducts of those glands, the *vasa deferentia* and ejaculatory ducts, together with their appendages, the *vesiculæ seminales*; 3, of the organs of copulation, the penis and its muscles; 4, lastly, of special accessory glands, the prostate and Cowper's glands.

§ 196. The testicles, *testes*, are two true glands, with a special covering, the *tunica albuginea* or *fibrosa*, in which are contained the secreting elements in the form of tortuous tubes, the tubuli seminiferi. The envelope (fig. 177, *e*) is a white membrane, dense and thick, whose structure is precisely similar to that of other fibrous membranes, especially resembling the dura mater. It forms a closed capsule, which everywhere invests the parenchyma of the testicle. Its outer surface is smooth and shining from a special covering (*tunica adnata*), except where the epididymis is applied to the testicle; whilst the inner surface is connected by a thin layer of loose connective tissue with the substance of the testicle, and penetrates also into the interior of the gland by means of a considerable number of processes. Among these, the most important is the *corpus Highmori s. mediastinum testis*, which passes from the posterior border of the testicle for about 3 to 4 lines into the interior; it is a perpendicular lamella of dense connective tissue, ⅔‴ to 1‴ in length, and of considerable thickness at its origin (fig. 177, *h*). Besides this, there are numerous smooth processes, septula testis (fig. 177, *o*), consisting of loose connective tissue, which arise from the entire inner surface of the tunica albuginea. They divide the gland into parts, and also serve to support the vessels; they converge from all sides towards the *corpus Highmori*, and attach

Fig. 177.

Transverse section through the right human testicle and its coats. *a*. *vaginalis communis*; *b*. vaginalis propria, outer lamella; *c*. cavity of the propria, which is absent during life; *d*. inner lamella of the propria (adnata) blended with *e*, the albuginea; *f*. passage of the propria upon the epididymis *g*; *h*. *corpus Highmorianum*; *i i i*. branches of the spermatic artery; *k*. internal spermatic vein; *l*. vas deferens; *m*. *arteria deferentialis*; *n*. lobuli testis; *o*. septula.

themselves to the borders and surfaces of it, by pointed extremities.

The glandular substance of the testicle is not homogeneous throughout, but consists of a certain number (100 to 250) of pear-shaped *lobules*, lobuli testis, which are not completely separated from each other; these converge by their apices towards the *corpus Highmori*; the shortest lobules are those which lie by the side of the septum, and the longest pass between the opposite borders of the organ (fig. 177, *n*). Each of these lobules is formed by one, two, or three seminal tubules, *tubuli s. canaliculi seminiferi*, $\frac{1}{8}'''$ to $\frac{1}{15}'''$ in thickness, which divide pretty frequently, and perhaps anastomose in their course. Taken together, they thus form a compact mass, in which the separate tubules terminate towards the thick end of the lobule, either in its interior or at its surface, by closed extremities or by loops (fig. 178). The seminal tubules of a lobule, although connected with each other by some connective tissue and vessels, can still be isolated to a great extent, or even entirely, by careful dissection, and the length of one of them is, according to *Lauth*, 13 to 33 inches. At the pointed end of each lobule, the seminal tubules become more straight, and then pass into the base of the *corpus Highmori*, either separately or by the union of the 2 to 3 coming from a lobule, to form one tube of $\frac{1}{10}'''$ in diameter. These have received the name of *ductuli recti*, and they form a very dense plexus, the *rete testis (rete vasculosum Halleri)*, 2 to 3 lines broad, and $1\frac{1}{2}'''$ thick, extending throughout the entire length of the organ. At the upper end of this plexus, the tubules measure from $0{\cdot}03'''$ to $0{\cdot}08'''$, and from them arise the excretory seminal tubules, *vasa efferentia testis s. Graafiana*. These are from 7 to 15 in number, and measure $0{\cdot}16'''$ to $0{\cdot}18'''$ in diameter. After penetrating the *tunica albuginea*, they pass on into the epididymis, and here they become attenuated to $\frac{1}{8}'''$ to $\frac{1}{10}'''$ in diameter, and again become convoluted in the same way as the seminal tubules within the lobules of the testis. They do not, however, form divisions and anastomoses, but each of the vasa efferentia, in its convoluted course, forms a body, conus vasculosus (*s. corpus pyramidale*), whose apex is directed towards the testicles. These coni vasculosi, connected with each other by connective tissue, compose the head of the epididymis, and from their tubules, which gradually coalesce with each other at the posterior and upper border of the epididymis, there

Fig. 178.

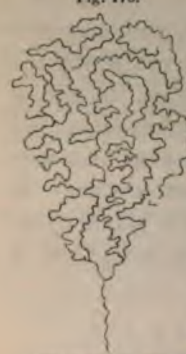

Diagram of the course of a seminal tubule.

then arises the simple canal of the epididymis, which measures 0·16‴ to 0·2‴ in thickness. This canal, wound in a well-known manner, forms the body and tail of the epididymis, and usually gives off from its lower end a cæcal process (*vas aberrans* of *Haller*). It then passes into the *seminal duct*, which is at first convoluted, and only $\frac{1}{4}$‴ to $\frac{1}{3}$‴ wide, but soon becomes straight and $\frac{3}{4}$‴ to 1‴ in diameter. The epididymis also possesses a fibrous coat of greyish-white colour, but this is very thin ($\frac{1}{6}$‴).

§ 197. *Structure of the Seminal Tubules, Sperma.*—The seminal tubules have a more solid wall in proportion to their diameter than other glandular canals, and they consist of a *fibrous coat* and an *epithelium*. The former has an average thickness of 0·003‴ to 0·004‴, but ranges between 0·0024‴ and 0·005‴. It is composed of connective tissue, indistinctly fibrillated, with longitudinal nuclei, no muscular fibres, and rarely with any indication of elastic fibrillæ: it is pretty firm and extensile. A simple layer of roundish or polygonal cells, 0·005‴ to 0·008‴ in diameter, with an occasional indication of a *membrana propria* beneath them, lies upon the inner surface of the tube, and completes the glandular canal, whose wall thus becomes of 0·007‴ to 0·01‴ in its total thickness. In young persons, these cells are pale and finely granular; but in older persons, more and more fat granules collect in them, and these soon occasion a slightly yellowish or even brownish colour of the seminal tubules. This condition of the tubules is very frequent even in men of middle age, and is invariably found in old persons.

Fig. 179.

Seminal tubule of man, magnified 350 times. *a.* fibrous coat with longitudinal nuclei; *b.* clear border, indicating, probably, a basement membrane; *c.* epithelium.

The *ductuli recti* possess the same structures as the tubules of the testicle; on the other hand, in the *rete testis*, a special fibrous coat cannot be distinguished, the canals here appearing more like spaces lined with epithelium in the dense fibrous tissue of the corpus Highmori. In the coni vasculosi, the fibrous coat again makes its appearance, and soon there is added a layer of smooth muscular fibres, which run in a transverse and longitudinal direction, and are recognisable in canals of $\frac{1}{5}$‴ to $\frac{1}{6}$‴ in diameter. The thicker parts of the canal of the epididymis are constructed exactly like the vas deferens (q. v.). The epithelium lining the epididymis has hitherto been regarded as a simple layer of cylindrical cells, but recently, *O. Becker* has made the interesting observation, that the chief part of this epithelium is of the ciliated variety. I have found the statements of this observer to be fully confirmed, in all essential respects, by an examination of the testicles of a suicide. Here, in the vasa efferentia, was seen a simple epithelium with cylindrical or conical cells (0·01‴ to 0·015‴ long), brownish nuclei in their interior, and cilia of 0·003‴ to 0·004‴ long. In the coni vasculosi the cells were similar, but somewhat longer, and the ciliated edge was 0·005‴ broad. At the entrance to the canal of the epididymis, extending as far as its middle, there appeared a single layer (*Becker* says several layers) of epithelium, whose cells were cylindrical, of enormous length (0·02‴ to 0·025‴), with delicate dark nuclei placed below the middle of the cell; the cilia were often grouped in tufts, and were as long as 0·01‴ to 0·015‴. In the middle of the epididymis, I remarked a few scattered cells of this sort, but I could not convince myself that these had not come off from a part higher up, especially as shorter cells without cilia were also found here. Cells, similar to those last mentioned, were contained also in the tail of the epididymis, and in the beginning of the vas deferens, only that many of those in the last situation showed a clear margin of greater width. I saw no ciliary action in this case; but I have satisfied myself of its existence in the lower mammalia, and I can confirm the observation of *Becker*, who saw it in the human testis after extirpation, that the direction of this action is towards the vas deferens.

The contents of the seminal tubules are not the same at all periods of life. In boys and young animals, there are found in the narrow tubules nothing but small clear cells, the outermost of which may be regarded as epithelial, though they are not always clearly distinguished from the others. At the period of sexual maturity, the elements contained in the seminal tubules increase in size simultaneously with the enlargement of the latter, and when the formation of the semen is actually established, they appear as clear, round cells, 0·005‴ to 0·03‴, and as cysts which inclose a variable number (1 to 10 or even 20, according to their size, fig. 181, *a*) of clear nuclei, 0·0025‴ to 0·0035‴ in diameter, with nucleoli. In many cases, an epithelium is not distinguishable at this period, the seminal tubules being wholly occupied by the above-mentioned cells; at other times, and more especially in those advanced in years, it is present, and then consists of fatty or pigmentary cells, which surround the other elements. These cells now, in whatever manner they appear, are the precursors of the *semen*, which, in the mature condition, is made up of an extremely small quantity of a viscid fluid, and innumerable small, linear corpuscles, named the *spermatic animalcules* or *spermatozoa (spermatozoids)*, which are endowed with peculiar movements. These spermatozoa are perfectly homogeneous, soft corpuscles, in which we may distinguish a thicker part, the *body* or *head*, and a filiform appendage, called the *thread* or *tail*. The former is flattened, pyriform when viewed from the side, with the pointed end directed forwards; seen from the surface, it is egg-shaped, or even rounded off anteriorly, whilst at the extreme anterior end, it is slightly hollowed like a cup, so that it appears at one moment clear, at another moment dark in the middle. The body is 0·0016‴ to 0·0024‴ in length, 0·0008‴ to 0·0015‴ in breadth, 0·0005‴ to 0·0008‴ in thickness, and, according as it lies upon the surface or upon the edge, its appearance is clearer or darker; it always has a peculiar fatty lustre, and presents a dark contour, especially when viewed from the side. The filament is colourless, and measures on an average 0·02‴ in length. It is flat and tapering; its greatest width is 0·0003‴ to 0·0005‴ at the end nearest the body, the union with which is effected by a constricted neck. The free extremity runs out into a very fine point, scarcely visible even by the best magnifying powers. In vigorous men, the semen in the whole course of the spermatic duct, and in the tail of the epididymis, is composed of these corpuscles, and occasionally of separate granules, nuclei and cells, which would appear to be here accidentally inter-

Fig. 180.

Human spermatozoa. 1. magnified 350 times; 2. magnified 800 times. *a*. seen from the side; *b*. from the surface.

Fig. 181.

Development of the spermatic filaments of the bull. *a*. sperm-cyst, and *b*, sperm-cells, containing nuclei, which exhibit a darker anterior and a clearer posterior part; *c*, *d*. the nuclei developing into spermatozoa; *e*. further stages; *f*. a filament almost complete, but still showing a little of the posterior clear zone in its body; also two perfect spermatozoa from the epididymis, one seen from the surface, the other edgewise; *g*. sperm-cells becoming pyriform, and about to liberate the contained spermatozoa. Magnified 450 diameters.

mingled: on the other hand, in the upper part of the epididymis, and in the testicle itself other elements preponderate, and at last, as we trace the semen to the place of its secretion, these cysts and cells come to form its sole constituents. The sperm-cells and cysts, as I call them, have a certain relation to the spermatozoa, and, indeed, as I have demonstrated recently, they actually give origin to them; one spermatozoon develops itself from each of their nuclei, the nucleus becoming elongated, and sending out a thread from one extremity. The proper seat of this development is in the testicle itself, so that, in the normal condition of the organ, we may be certain of finding in its internal parts developed spermatozoa in their mother-cells; and these may often be seen in all the seminal tubules without exception. In the normal course of development, the spermatozoa do not become free in the testicle itself, or do so only in very small numbers; hence, the seminal tubules are far from being the place in which to seek the spermatozoa (although, even here, they will never be missed when water is added, because, by this reagent, the enclosing parts are ruptured). The spermatozoa should rather be sought in the *rete testis* and *coni vasculosi*, for here it is that the sperm-cells burst. The spermatic filaments, while included in the cell, have a regular arrangement into bundles, which are curved, so that the heads and the tails of the filaments come together. This is seen when there are many (10 to 20) filaments in a cell; when they are present in smaller numbers, they lie across each other without any regularity. At last, by the rupture of the including cells and cysts, the spermatozoa become free, and entirely fill the epididymis in dense swarms; here they are found isolated or in bundles, the latter, however, speedily breaking up into their components. In the lower part of the epididymis the whole process of development is, as a rule, completed; still it not unfrequently happens, that a few intermediate forms receive a further development, and arrive at their complete formation only when they reach the spermatic duct. It is also worthy of note, that the spermatic filaments, when they are contained singly in separate cells, frequently give to the cell a peculiar pyriform outline (fig. 181, *g*), and often simply break through the side of the cell, so that a larger or smaller fragment of the cell remains behind in the form of a ragged cap on the head of the spermatozoon, or of a round appendage on its tail: we may often see the great majority of the spermatozoa in the epididymis provided with such appendages on their tails, and these may be recognised even in the matured semen.—For further details on the spermatic cells and their mode of development, I refer to my treatise in *Zeitschr. f. wiss. Zool.* vii.

Considered as a whole, as it is found in the vas deferens, the semen is a whitish, viscid, odourless material, which consists almost entirely of spermatozoa, with an extremely small quantity of a connecting fluid between them. The chemical composition of this pure semen has not yet been investigated in man; but we learn from *Frerichs*, that in the semen of a carp, the liquid portion contains a small quantity of alkali in combination with sulphuric and phosphoric acids; while the spermatozoa consist of a protein substance (binoxide of protein, *Frerichs*), and also contain 4·05 per cent. of a fat resembling butter, and 5·21 per cent. of phosphate of lime. I myself have found in the mature semen of the bull, water, 82·06, solids, 17·94 per cent.. The latter were composed of 13·138 albuminous bodies of spermatozoa, 2·165 of phosphuretted fat, and 2·637 of salts. The emitted semen is a mixture of pure semen, with secretion of the vesiculæ seminales, prostate and Cowper's glands. It is colourless and opalescent, has an alkaline reaction, and peculiar odour. Immediately on emission, it is viscid and ropy like white of egg, but on cooling it is of the consistence of jelly, and after a while becomes thin and fluid. Microscopically examined, the spermatozoa are seen to be contained in a considerable quantity of clear fluid, which, on the addition of water, assumes the form of irregular flakes and shreds; this undoubtedly comes chiefly from the *vesiculæ seminales*. This gelatinising substance, which *Henle* designated as fibrine, and *Lehmann* regards as albuminate of soda, has received from *Vauquelin* the name of *spermatin*. This chemist analysed human emitted semen, and found six per cent. of this substance, partly in the dissolved form, partly constituting the substance of the spermatozoa. The other constituents were three per cent. of earthy phosphate, one per cent. of soda, and the remaining ninety per cent. water. If the semen be dried, the spermatozoa are usually found uninjured, the large quantity of lime which they contain enabling them, it appears, to resist destruction. Numerous crystals of ammoniaco-magnesian phosphate are formed in the dried semen among the spermatic filaments. In stains of semen, even after a long period, their filaments can be recognized on the addition of a little water; they resist decomposition for a long while when kept in water, or even in a putrefying animal liquid; thus *Donné* saw them in putrid urine which had been kept for three months. It is stated by *Valentin*, that they even retain their form unchanged when heated to redness.—The following results were obtained by an examination of the spermatic filaments of the bull. Concentrated sulphuric acid gives a yellowish colour to the semen, but in twenty-four hours is found not to have dissolved the spermatozoa. With grape-sugar and sulphuric acid, the semen becomes a purplish-red, but the colour only affects the substance between the filaments. Strong nitric acid colours the semen yellow, the filaments to some degree, as well as the amorphous portion, but beyond a slight shrivelling, the spermatozoa undergo no other change from this re-agent in twenty-four hours. Even when boiled for two minutes with nitric acid, the filaments are not dissolved. Hydrochloric acid in the cold produces no alteration in them: boiled with this acid, the spermatozoa remain recognizable, but they become remarkably pale, and their tails appear shrivelled. Boiled with Millon's reagent (nitrate of mercury) the semen assumes a more or less deep shade of red, and the filaments themselves are somewhat coloured. Glacial acetic acid produces no effect either in the cold or after prolonged boiling, and the spermatozoa will keep for weeks in this acid. A much more powerful influence than that of the acids is exerted by the caustic alkalies; but even these have very little power in the cold, whatever the strength of the solution. At higher temperatures the filaments dissolve, the tails first, and the bodies much more slowly, and it takes a long time to dissolve them altogether, even when the solution contains fifty per cent. of alkali. The conclusion from these reactions is, that the substance of the spermatic filaments of mammalia (on that of other vertebrata, see my treatise before quoted) is not a body of an albuminous nature, but rather that it has affinities with the substance which composes the wall of cell-nuclei and elastic fibres; it is not, however, so very difficult of solution in caustic alkali as the elastic fibre.

The movements of the spermatozoa are not often to be seen in the unmixed semen, as it is too concentrated; they usually occur first in the mixed secretion contained in the vesiculæ seminales and in emitted semen, or they are seen when pure semen is diluted. These movements are effected solely by alternate curvings together and extensions of the filiform appendages, constituting a serpentine movement. The changes of position thus produced, at any rate in man and in mammalia, are so rapid and diverse, crawling, twisting, and twitching, the head always moving in advance of the tail, that the elements of semen were formerly regarded as animalcules. The duration of the movements depends upon various circumstances. In the dead body, they are not unfrequently observed twelve to twenty-four hours after death (*Valentin* once saw slight movements after eighty-four hours). In the female genitals in mammalia, they continue to move even after seven and eight days. Water and all diluted solutions, render the movements more active at first; but they soon cease, and the filaments not unfrequently roll up in the form of loops: the spermatozoa, however, are not then dead, as has hitherto been believed, for they will resume their activity, as I have proved, on the addition of concentrated solutions of salts, sugar, albumen, or urea. All animal fluids of an alkaline reaction and moderate concentration, are favourable to the movement of the filaments, while acid solutions or those which are too weak—such as urine, sour milk, sour mucus, diluted bile—exercise an injurious effect upon them. Solutions of substances of a more neutral character, such as sugar, albumen, glycerine, amygdalin, or urea, are harmless if they are of a medium degree of strength, but are injurious if they are too concentrated or too diluted. In either of the latter cases, the suspended movements can be restored by bringing the solution to a suitable degree of dilution. In a similar way, the spermatozoa are effected by the neutral salts of the alkalies; common salt in a solution of one per cent., Glauber's salts, or Epsom salts, in a solution of three per cent., are all favourable to their movements. Stronger or weaker solutions suspend the movements, though these may be restored in the way before mentioned. Acids, metallic salts, and caustic alkalies, are harmful to the movements of the spermatozoa, though it appears from my observations, that the injurious influence of the last-named reagents is preceded by a period of excitement, of more active motion, so that caustic potash and soda might be taken for special excitors of the filaments. Narcotic substances only act injuriously when they have some chemical influence on the semen, or when they are of an unsuitable degree of dilution. Alcohol, æther, oil, creosote, chloroform, tannin, among other matters, have been found to injure the movements. For further detail, the reader may consult my treatise and the researches of *Quatrefages*. The effect of cold is to suspend the movements, and a temperature of 42° to 45° Reaumur (116° to 124° Fahr.) has a similar result: but spermatozoa whose movements have been arrested by cold, will move again on a return of warmth, if the temperature have not been reduced too low.

The formation of the spermatozoa and semen ceases, as a rule, in advanced age, yet spermatozoa and even capability of procreation are not unfrequently found in men sixty, seventy, or even eighty years old. *Duplay* found spermatozoa thirty-seven times in fifty-one men between sixty and eighty years of age. In twenty-seven of these, they were quite normal, in the others, deformed by the loss of their tails. After diseases, the spermatozoa are just as frequently found as not; and all that can be said with reference to the cause of their absence in such cases is, that it seems to depend chiefly upon the disturbance of nutrition.

§ 198. *Coverings, Vessels, Nerves of the Testicle.*—The testicle, together with its fibrous coat and a part of the epididymis, are directly inclosed by the special serous tunic (*tunica vaginalis propria*, fig. 177, *b d f*). This is a thin serous membrane, which was in its origin a part of the peritoneum, and corresponds with it in structure. Its epithelium is composed of a layer (0·005‴ in thickness) of clear polygonal cells, 0·005‴ to 0·008‴ in size, with beautiful nuclei, and here and there a few pigment granules of yellowish hue. On the testicle itself, the epithelium is immediately situated upon the fibrous coat, being inseparably blended therewith, and constituting the so-called *tunica adnata testis*, or the visceral lamina of the tunica vaginalis propria. Over the epididymis, however, the serous membrane can be distinctly isolated, as in the parietal lamina of the tunica vaginalis, and it here consists of dense connective tissue, intermingled with elongated nuclei. The *general vaginal tunic of the testicle, tunica vaginalis communis* is a dense membrane of some thickness, which closely surrounds the serous sac, and forms a 'common' envelope to the testicle, the epididymis at its lower end, and the spermatic cord. On the testicle, it consists of firm connective tissue, but higher up it is a looser net-work, and has many elastic fibres. Between this envelope and the parietal layer of the serous membrane, and on the epididymis, is found a layer of smooth muscular fibre, spread over the lower two-thirds of the testicle. This is firmly connected, both with the common envelope just described and the proper tunica vaginalis, and may be called the *inner muscular coat of the testicle;* the cremaster, which is made up of transversely striated fibres, being inserted into the outer side of this muscular layer. Finally, the whole of the parts hitherto mentioned are enclosed in the scrotum, which consists of the tunica dartos (§ 36), or *outer muscular coat of the testicle,* loosely connected with the common vaginal tunic, and the external skin: this is here characterised by its thinness, the absence of fat, the colour of its epidermis, and the large size of its sebaceous and sudoriparous glands.

The blood-vessels of the testicle and epididymis are derived from the long and slender internal spermatic artery, which runs in the spermatic cord, and proceeds from its posterior border to the testicle. Arrived here, some branches of the artery penetrate at once into the corpus Highmorianum, while others split up into numerous tortuous twigs, which pass along the inner surface of the tunica albuginea and in its substance, in their course towards the anterior border of the testicle. The coarser ramification in the parenchyma of the testicle proceeds in part from the corpus Highmorianum, in part from the tunica albuginea along the septula testis. From these sources, numerous small vessels pass into the interior of the lobules, and form a wide net-work of capillaries, 0·003‴ to 0·008‴ in width, around the seminal tubules. On the epididymis, a similar net-work, but more scanty, is met with, and in the formation of this, the *art. deferentialis*, is also concerned. The scrotum, on the other hand, and the vaginal tunics, are richly supplied with vessels by the scrotal and external spermatic arteries. The veins are but a repetition of the arteries, and as for the *lymphatics*, they are very numerous in the scrotum, and in the vaginal tunics, and, according to the beautiful investigations of *Panizza* (*Osservazioni*, tab. viii.), confirmed by *Arnold*, the lymphatics of the testicle itself are also very fully developed. They come partly from the interior, partly from the surface of the testicle and epididymis, form beautiful net-works beneath the tunica adnata, and finally lead to the lumbar glands by means of several trunklets, which are situated in the spermatic cord, and connected with those of the vaginal tunics.

The nerves of the testicle are but scanty, and arise from the internal spermatic plexus. They accompany the arteries to the testicle, but their course in the interior I have in vain endeavoured to investigate, as it is rare to see dark-bordered nerve-fibres, even along with the larger arteries of the parenchyma.

Bundles of muscular fibres, like those described by me in the inner muscular coat of the testicle, occur, also, according to *Rouget*, in the tunica albuginea, and even in the septula testis. The so-called hydatids of *Morgagni* on the head of the epididymis have been examined by *O. Becker*, who finds that they always contain ciliated epithelium, not only when they have a connection with the seminal tubules of the epididymis, but even when they are entirely closed.

§ 199. *Vasa Deferentia; Vesiculæ Seminales; Accessory Glands; Organ of Giraldès.*—The spermatic ducts, *vasa deferentia*, are cylindrical canals, 1 line to $1\frac{1}{2}$ in average width, with walls $\frac{1}{2}'''$ to $\frac{2}{3}'''$ in thickness, and with a cavity $\frac{1}{4}'''$ to $\frac{1}{3}'''$ in diameter. They are composed, on the outside, of a thin fibrous coat, next to this a layer of smooth muscular fibres, and, most internally, a mucous membrane. The muscular coat, 0·38''' to 0·6''' in thickness, possesses an external thick layer of longitudinal fibres, a middle layer of equal thickness, whose fibres run transversely and obliquely, and an inner thin layer, which amounts to only one-fifth of the entire thickness of the muscular coat; this coat consists of rigid and pale fibre-cells, measuring up to 0·1''' in length, 0·004''' to 0·006''' in average breadth, intermingled with some connective tissue and a few very pale elastic fibrillæ. The mucous membrane, 0·12''' in thickness, is white, puckered longitudinally, and is provided with numerous reticulated depressions of various sizes in the last or broadest segment of the duct. Its outer two-thirds are whiter, and contain one of the densest networks of elastic fibrils that I know of; whilst, internally, this is replaced by a clearer, thinner layer of connective tissue, indistinctly fibrillated, and containing nuclei. Upon this layer of the mucous membrane rests a simple stratum of pavement-epithelium, composed of cells 0·005''' to 0·008''' in size, which invariably contain brownish pigment-granules in some number; these impart a yellowish colour to the inner surface of the mucous membrane. The vessels of the spermatic ducts are very distinct in the external fibrous coat, though they also penetrate into the muscular and mucous coats, and form, in both, loose networks of capillaries, 0·003''' to 0·005''' in width. According to *Swan* (*Nerves of the Human Body*, pl. v. 82, pl. vi. 81), the nerves of the spermatic duct in the pelvic cavity are numerous but delicate, and are connected with the lateral and middle nerves of the bladder and rectum, as well as with the hypogastric plexuses. I have likewise seen these nerves, and have found them to contain fine fibres and fibres of *Remak*, but have not been able to trace them into the interior.

The ductus ejaculatorii and the vesiculæ seminales appear to be similar in their construction to the spermatic ducts, the vesiculæ being, as is well known, nothing but cæcal appendages of the vasa deferentia, furnished with wart-like tubular, or even ramified processes. The ejaculatory ducts present in their upper part the same muscular structure as the spermatic duct, only that their walls are more delicate. Towards the prostate gland, their coats become still more attenuated, but present, even at the extreme termination, muscular fibres, intermingled with a considerable quantity of connective tissue and elastic fibrillæ. The seminal vesicles have their walls considerably thinner than those of the spermatic ducts, but possess a similar structure; the mucous membrane, which is very vascular, is covered all over with reticulated depressions. The seminal vesicles are surrounded externally by an envelope, which is composed, in part, of connective tissue, and, in part, especially upon the posterior surface, of distinct muscular fibres. This envelope also extends inwards, between the separate convolutions of these canals, and unites them, while at the lower ends of the seminal vesicles, it passes from one to the other as a broad muscular band; this has been recently observed also by *V. Ellis,* who calls this band the *compressor vesiculæ et ductus seminis.* The contents of the seminal vesicles consist, normally, of a clear fluid, somewhat viscid in consistence, which coagulates immediately after death into a soft jelly, but subsequently becomes again quite fluid. This contains a protein compound, easily soluble in acetic acid, which is obviously identical with that contained in the fluid of the ejaculated semen. In common with many other observers, I have frequently found spermatozoa in the seminal vesicles, although the main function of these appendages is doubtless secretory. The nerves of the seminal vesicles are derived from the sympathetic and spinal cord, and spring directly from the dense *plexus seminalis,* whose fibres partly enter into the coats of the seminal vesicles, partly pass to the prostate gland, and are not further traceable. The prostatic plexus, thus formed, is reinforced by filaments from the vesical and lower pelvic plexuses.

The prostate, according to my own observations, which are confirmed by *V. Ellis*, and partly also by *Jarjavay*, is a very muscular organ, the glandular substance scarcely constituting more than one-third, or the half of the entire mass. Proceeding from within outwards, we first meet with the thin mucous membrane, whose epithelium is composed of two layers of cylindrical cells, and in intimate connection with this membrane we next observe a yellowish layer of longitudinal fibres, which partly extends from the *trigonum vesicæ* to the *caput gallinaginis*, but is, in another part, unconnected with the muscles of the bladder; this layer consists of connective tissue, elastic fibrillæ, and smooth muscular fibres in equal proportions. It is followed by a thick stratum of circular fibres of the same structure, which is connected with the sphincter vesicæ, and extends as far as the *caput gallinaginis*, and which I have named the *sphincter prostatæ*. Having removed these different muscular layers, we at last come upon the proper glandular tissue of the prostate, which, accordingly, we find to occupy chiefly the outer parts of the organ, although, it is true, some few lobules do penetrate among the circular fibres, and the numerous excretory ducts traverse the longitudinal and transverse fibres, to open right and left, parallel to the caput gallinaginis. The proper substance of the prostate consists of a reddish-grey material, somewhat dense, which may be very readily split up into fibres in the direction of the diameter of the organ, or more correctly, the structure may be described as radiating in all directions, from the lateral parts of the caput gallinaginis towards the outer surface of the organ. The elements of this proper tissue of the prostate are, first, distinct muscular fibres of the smooth variety, in separate thick bundles, with some connective tissue; and, secondly, the true glands of the organ. The latter consist of thirty to fifty compound racemose glands, of a conical or pear-shaped form, which are distinguished from the ordinary racemose glands by their loose structure, the distinct pedunculation of many of their vesicles, and the slight development of the smallest lobules; this last circumstance appears to be partly ascribable to the abundance of fibrous tissue, interspersed among the elements of the glands. The *gland-vesicles* are pyriform or roundish, 0·05‴ to 0·1‴ in size, and lined by an epithelium, whose cells are polygons or short cylinders, 0·004‴ to 0·005‴ in length, and contain brown pigment-granules. On the excretory ducts, however, the epithelium has the same cylindrical form as is present in the prostatic part of the urethra. The secretion of the prostate appears to be similar to that of the seminal vesicles; at least, the prostatic calculi, as they are termed, consist of the same protein substance, soluble in acetic acid, as is met with in the seminal vesicles (*Virchow*). These calculi are round, concentric concretions, 0·03‴ to 0·1‴ in size, formed in the gland-vesicles. The prostate possesses a fibrous tunic, which firmly encloses the glandular tissue, and contains smooth muscular fibres in large quantity. The organ is provided with a considerable number of vessels, the most remarkable of which are the numerous capillaries surrounding the glandular elements, and a rich venous plexus beneath the mucous membrane of the urethra. The nerves have been mentioned above; their course in the interior of the prostate is unknown.

The *uterus masculinus*, or the *vesicula prostatica*, is situated in the caput gallinaginis, and between the ejaculatory ducts. Its walls are yellowish-white, and lined by a cylindrical epithelium. The chief microscopical elements are connective tissue and elastic fibrils, with which smooth muscular fibres are intermingled; in the cervix of the vesicle these are less numerous than in the fundus, where they are found in considerable amount.

The glands of *Cowper* are compact, compound racemose glands, whose terminal vesicles, 0·02‴ to 0·05‴ in size, are lined by a pavement-epithelium, whilst in their excretory ducts the epithelium is cylindrical. The delicate envelope surrounding the entire gland, as well as the fibrous stroma in the interior, is tolerably rich in smooth muscular fibres, and I have recently detected these even on the excretory ducts (whose width is ¼‴), as a delicate, longitudinal layer. The secretion of these glands, which can be readily obtained from the excretory ducts, is ordinary mucus.

The organ of *Giraldès* (*corps innominé*, *Giraldès*) is, according to the observations of *Sharpey* and myself, a small linear body, situated at the upper end of the testicle in the spermatic cord, and extending along the cord on the side farthest from the vas deferens. It is about half an inch long, and is of a whitish colour; on microscopical examination, it is found to consist of a good number of isolated elements, in the form of tubules and vesicles of very various shapes; these are held together by a connective tissue with blood-vessels. The tubules are either simple, straight or twisted, or they are furnished with processes in such numbers, that they look like portions of the prostate or of an embryonic parotid. Here and there simple tubes exhibit dilatations, and these may become so distinct as to give the appearance of separate vesicles. The canals of this organ, whatever their form, all consist of an envelope of connective tissue with a pavement-epithelium, in the cells of which, in grown persons, I find a good deal of fat. Contained in the tubules is a fluid, more or less clear. This organ attains its greatest development, according to *Giraldès*, in boys from six to ten years of age; this observer regards it, and he is doubtless right, as the remains of the Wolffian body, analogous to the 'appendage to the ovary' of the female. It still remains to be discovered whether this organ may not be connected at its lower end with the epididymis; and, in this case, it might be considered to be nothing more than a peculiar and contorted *vas aberrans*.

L. Fick has recently made the statement, that the muscular structure of the vas deferens is not composed of isolated fibre-cells, but of a continuous web. It is true that the fibre-cells are less readily separated from each other here than elsewhere, but they do, nevertheless, exist as such; and *Fick* will probably convince himself of this, if he will re-examine these elements with the aid of re-agents.

§ 200. The *Organs of Copulation* in the male consist of the penis, an organ composed of three erectile vascular bodies, named spongy or cavernous, *corpora spongiosa seu cavernosa*. These are attached to the pelvis, and perforated by the urethra; they are covered by special fasciæ and by the external skin, and are provided with three special muscles.

The *corpora cavernosa penis* are two cylindrical bodies, divided posteriorly, but coming together in front, where they are separated only by a simple incomplete partition. In them we may distinguish a special fibrous tunic (*tunica albuginea s. fibrosa*), and the internal spongy tissue. The former is a white, lustrous, firm membrane, half a line thick, and forms the dissepiment, as well as the outer envelope of the spongy bodies. The partition between the corpora cavernosa, where they meet anteriorly, has the form of a thin membrane broken up into separate fibres and laminæ, and consists of ordinary fibrous tissue, with numerous, well-developed, fine elastic fibres, as in tendons and ligaments. Within this lies the spongy tissue, of a reddish colour, consisting of innumerable fibres, trabeculæ, and laminæ, which are united to form a fine meshwork, with small roundish or angular spaces, anastomosing with each other in all directions. These are named the venous spaces of the cavernous bodies, and, during life, are filled with blood; thus the structure bears a remarkable resemblance to a sponge. All the trabeculæ invariably possess a perfectly uniform structure. Externally, they are covered by a simple layer of pavement epithelial cells, intimately connected, and often inseparable — the *epithelium of the venous spaces*; upon this follows the proper fibrous tissue, which is composed of almost equal parts of connective tissue, with fine elastic fibres, and of smooth muscular fibres; in the interior of many trabeculæ, but by no means in all, are enclosed arteries and nerves of various sizes. The muscular elements of the trabeculæ are distinctly recognisable by their very characteristic nuclei, which appear on the addition of acetic acid; but the cells themselves may be isolated in large numbers, especially after treatment with nitric acid of 20 per cent., and they then appear as fibre-cells, 0·02‴ to 0·03‴ in length, and 0·002‴ to 0·0025‴ in breadth.

The *corpus spongiosum urethræ* is constructed in essentially the same manner as the spongy body of the penis, but with some differences of detail: first, the fibrous tunic (which also presents the appearance of a partition in the bulb), is much thinner, not so white, and is richer in elastic elements; 2. the venous spaces are narrower, and narrowest of all at the glans; 3. lastly, the trabeculæ are more delicate, and have more elastic fibrillæ beneath the epithelium, but, in other respects, they are constructed as in the corpora cavernosa penis.

In this place we have also to speak of the male urethra. In a portion of its length this is an independent canal, but at its beginning, and at its end, it consists only of a channel lined by mucous membrane, and supported by the prostate and the spongy structure of the urethra. The mucous membrane is placed on a layer of connective tissue, which has a longitudinal direction, and contains numerous elastic fibrillæ. In the prostatic part of the urethra, these elements, with the epithelium, make up the entire membrane. In the isthmus, or membranous part, too, there is very little else, although a few ill-developed, smooth muscular fibres may be found in a longitudinal and transverse direction, mixed with the ordinary fibrous tissue; on this there follow the striped fibres of the *musculus urethralis*. In the cavernous portion of the urethra, the submucous tissue also contains a few scattered fibres of the same kind, and, for a certain depth, we always meet with longitudinal fibres of connective tissue, which have more or less of these plain muscular fibres among them; this tissue appearing to belong to the urethra, and not to the cavernous body, since it is without venous spaces, and forms, indeed, a continuous membrane, which limits the proper cavernous structure from the mucous membrane of the urethra. The epithelium of the urethra consists of a superficial stratum of pale cylindrical cells, 0·012''' in size, and, beneath these, one, or perhaps two layers of small cells, round or oblong. At the anterior half of the fossa of *Morgagni*, there are found papillæ of 0·03''' in length, with a lamellated pavement-epithelium of 0·04''' in thickness. According to *Jarjavay*, these papillæ pass backwards for a distance of 4''' to 8''', or even as far as 18''', and stand in rows on a triangled area, which gets narrower behind and above. In the isthmus, and in the cavernous portion of the urethra, there occur a large number of little glands, $\frac{1}{3}'''$ to $\frac{1}{2}'''$ in diameter, named Littre's glands. These correspond, in all essential particulars of structure, with the ordinary racemose glands. Simpler forms of such glands are occasionally met with *among the more complex*, and, in the pars prostatica, the place of these glandules is supplied by small mucous follicles, like those above described in the cervix vesicæ. The epithelium of all these glands is cylindrical, but in the ducts it merges into the tesselated variety. The secretion is common mucus, which often collects in quantities in enlargements of the gland-tubes.—Small fossæ of the mucous membrane, which are not uniformly present, have received the name of *lacunæ Morgagnii*; but in these I have not been able to perceive anything of a glandular nature.—The *fascia penis* is a membrane rich in fine elastic fibres, which invests the penis from its root to the glans. At the root it is connected with the fascia of the perineum and inguinal region, and also takes part in the formation of the suspensory ligament of the penis, which proceeds from the symphysis pubis to the dorsum of the organ, and abounds in true elastic tissue. Externally, the fascia is continued uninterruptedly into the skin. The integument of the penis, as far as the free border of the prepuce, possesses the ordinary structure of the cutis, though it is distinguished by its delicacy, and by the occurrence of a layer of smooth muscular fibres beneath it, as far as the prepuce. These fibres are a continuation of the tunica dartos into the subcutaneous tissue of the penis, which is abundant and wanting in fat. From the prepuce onwards, the integument of the penis assumes more and more the nature of a mucous membrane, it becomes much thinner, and no longer possesses hairs and sudoriparous glands, though it has well-developed papillæ. On the glans, the membrane is intimately connected with the spongy body, and is still provided with a soft epidermis, of 0·035‴ to 0·056‴ in thickness (see § 44, fig. 40, 4). The sebaceous glands in this situation, which form the preputial sebaceous matter, are peculiar in their characters, and are named *glandulæ Tysonianæ*.

The arteries of the penis arise from the pudic, and present no peculiarities, except in their distribution to the corpora cavernosa. These bodies receive their supply in the main from the deep arteries of the penis, as well as a few small branches from the dorsal artery. The larger arterial trunks run close to the septum, and are surrounded by a sheath of connective tissue, connected with the trabecular network. Giving off a small branch to the bulbs of the corpora cavernosa, these vessels are directed forwards, distributing numerous branches to the spongy tissue. These branches run in a tortuous manner in the substance of the trabeculæ, occasionally anastomosing, and divide, until they become capillaries of 0·006‴ to 0·01‴ in diameter, which open directly into the venous spaces, without forming a capillary network. The tortuous direction of the arteries in the trabeculæ is probably lost at the period of erection. In the posterior part of the penis there are found numerous arterial trunks, of 0·04‴ to 0·08‴ in diameter, peculiarly bent and convoluted; they were discovered by *J. Müller*, and are named *arteriæ helicinæ*. They usually lie together in groups of from three to ten, and do not end by cæcal termination, as was at first supposed; but they give off, I find, from their club-shaped ends, fine vessels, 0·006‴ to 0·01‴ in diameter, which run further and terminate in the sinuses, like the other twigs of the arteries. The corpus spongiosum urethræ is supplied by the *arteriæ bulbosæ*, *bulbo-urethrales*, and *dorsales*, and the distribution of the vessels in it is exactly the same as has just been described; and helicine arteries also occur in the bulb of the urethra. The veins commence, if we may so speak, by the anastomosing venous spaces, from which the blood passes into the outer veins provided with special walls (the *v. dorsalis*, *v. profundæ* and *bulbosæ* especially), through the intervention of short efferent canals, which are numerous, and arise in various ways from the venous spaces. The lymphatics form very dense and fine networks in the integument of the glans, in the prepuce, and in the rest of the skin, and lead to the superficial inguinal glands by means of trunks which accompany the dorsal vessels. According to *Mascagni*, *Fohmann*, and *Panizza*, the interior of the glans around the urethra also possesses numerous lymphatics, which run backwards upon the urethra, and pass into the pelvic glands. The nerves of the penis arise from the pudic nerve and the cavernous plexus of the sympathetic; the former of these chiefly supplies the skin and the mucous membrane of the urethra. The cavernous bodies are supplied from the pudic only to a slight extent, the sympathetic nerve being specially distributed to these structures. The terminations of the nerves in the skin and mucous membrane present the same arrangement as usual in those tissues; numerous divisions especially, and slight indications of tactile corpuscles, are found in the glans. The terminations of the nerves in the corpora cavernosa are not yet known, though nerves with fine tubes and fibres of *Remak* are easily demonstrable in the trabeculæ.

Fig. 182.

A small artery of the corpus cavernosum penis, of the man, injected, and magnified 30 times, giving off two arteriæ helicinæ, terminating in smaller vessels.

in advanced age, yet spermatozoa and even capability of procreation are not unfrequently found in men sixty, seventy, or even eighty years old. *Duplay* found spermatozoa thirty-seven times in fifty-one men between sixty and eighty years of age. In twenty-seven of these, they were quite normal, in the others, deformed by the loss of their tails. After diseases, the spermatozoa are just as frequently found as not; and all that can be said with reference to the cause of their absence in such cases is, that it seems to depend chiefly upon the disturbance of nutrition.

§ 198. *Coverings, Vessels, Nerves of the Testicle.*—The testicle, together with its fibrous coat and a part of the epididymis, are directly inclosed by the special serous tunic (*tunica vaginalis propria*, fig. 177, *b d f*). This is a thin serous membrane, which was in its origin a part of the peritoneum, and corresponds with it in structure. Its epithelium is composed of a layer (0·005''' in thickness) of clear polygonal cells, 0·005''' to 0·008''' in size, with beautiful nuclei, and here and there a few pigment granules of yellowish hue. On the testicle itself, the epithelium is immediately situated upon the fibrous coat, being inseparably blended therewith, and constituting the so-called *tunica adnata testis*, or the visceral lamina of the tunica vaginalis propria. Over the epididymis, however, the serous membrane can be distinctly isolated, as in the parietal lamina of the tunica vaginalis, and it here consists of dense connective tissue, intermingled with elongated nuclei. The *general vaginal tunic of the testicle, tunica vaginalis communis* is a dense membrane of some thickness, which closely surrounds the serous sac, and forms a 'common' envelope to the testicle, the epididymis at its lower end, and the spermatic cord. On the testicle, it consists of firm connective tissue, but higher up it is a looser net-work, and has many elastic fibres. Between this envelope and the parietal layer of the serous membrane, and on the epididymis, is found a layer of smooth muscular fibre, spread over the lower two-thirds of the testicle. This is firmly connected, both with the common envelope just described and the proper tunica vaginalis, and may be called the *inner muscular coat of the testicle*; the cremaster, which is made up of transversely striated fibres, being inserted into the outer side of this muscular layer. Finally, the whole of the parts hitherto mentioned are enclosed in the scrotum, which consists of the tunica dartos (§ 36), or *outer muscular coat of the testicle*, loosely connected with the common vaginal tunic, and the external skin: this is here characterised by its thinness, the absence of fat, the colour of its epidermis, and the large size of its sebaceous and sudoriparous glands.

The blood-vessels of the testicle and epididymis are derived from the long and slender internal spermatic artery, which runs in the spermatic cord, and proceeds from its posterior border to the testicle. Arrived here, some branches of the artery penetrate at once into the corpus Highmorianum, while others split up into numerous tortuous twigs, which pass along the inner surface of the tunica albuginea and in its substance, in their course towards the anterior border of the testicle. The coarser ramification in the parenchyma of the testicle proceeds in part from the corpus Highmorianum, in part from the tunica albuginea along the septula testis. From these sources, numerous small vessels pass into the interior of the lobules, and form a wide net-work of capillaries, 0·003‴ to 0·008‴ in width, around the seminal tubules. On the epididymis, a similar net-work, but more scanty, is met with, and in the formation of this, the *art. deferentialis*, is also concerned. The scrotum, on the other hand, and the vaginal tunics, are richly supplied with vessels by the scrotal and external spermatic arteries. The veins are but a repetition of the arteries, and as for the *lymphatics*, they are very numerous in the scrotum, and in the vaginal tunics, and, according to the beautiful investigations of *Panizza* (*Osservazioni*, tab. viii.), confirmed by *Arnold*, the lymphatics of the testicle itself are also very fully developed. They come partly from the interior, partly from the surface of the testicle and epididymis, form beautiful net-works beneath the tunica adnata, and finally lead to the lumbar glands by means of several trunklets, which are situated in the spermatic cord, and connected with those of the vaginal tunics.

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Bundles of muscular fibres, like those described by me in the inner muscular coat of the testicle, occur, also, according to *Rouget*, in the tunica albuginea, and even in the septula testis. The so-called hydatids of *Morgagni* on the head of the epididymis have been examined by *O. Becker*, who finds that they always contain ciliated epithelium, not only when they have a connection with the seminal tubules of the epididymis, but even when they are entirely closed.

in a fruitful intercourse), up to the ovum and into its substance. That the spermatozoa are the proper fecundating elements of the semen, has been placed beyond the slightest doubt by the observations of *Prévost* and *Dumas*, *Schwann* and *Leuckart*, on the semen after filtration, and, above all, by the recent discoveries of *Newport* (*Philos. Trans.*, 1853, ii. p. 233). The last-named author also establishes the fact, that the spermatozoa actually penetrate the substance of the ovum, as was asserted many years before by *Barry*; and on this point, various subsequent observers have confirmed the statements of *Newport* (on the rabbit and frog, in fishes and insects). Now that we are acquainted with the passage of the spermatozoa into the ovum, we can no longer regard their fecundating power as being a *dynamic influence*, as was formerly supposed, from the circumstance that moving filaments alone can fecundate; on the contrary, it now appears probable that the *material* of the spermatozoa becomes actually mingled with the yelk, and thus renders it capable of development. Let it be remembered, however, that we are still far from being in a position to maintain a similar penetration of the ovum by the spermatozoon in the whole animal series, so that we must be careful how we put forth any theory of fertilisation as being equally applicable in all cases.

The ejaculation of the semen is effected in the main by the vasa deferentia, with their powerful muscular apparatus. These organs have been seen by *Virchow* and myself, on the body of an executed criminal, to contract and shorten with remarkable energy under the influence of galvanism; and the same action is witnessed in the seminal vesicles, the very muscular prostate, and the striated muscular fibres of the urethra and penis. The erection of the penis is effected, as I have shown (*Würz. Verh.*, vol. ii.), by a relaxation of the muscular fibres in the trabeculæ of the cavernous and spongy bodies, and in the middle coat of the arteries of those parts; as a consequence of this relaxation, the spongy tissue, like a sponge which has been compressed, dilates and fills itself with blood. Rigidity appears as soon as the muscular fibres are entirely relaxed and the venous sinuses completely filled, without there being any need for the return of blood being impeded, or the circulation stopped. It disappears when the muscles contract again, the venous spaces becoming narrow, and the blood being pressed out of them. In an executed criminal, we have recently found very energetic contraction, upon the application of electric stimuli to the exposed spongy tissue of the corpora cavernosa. During the ejaculation of the semen, the ischio-cavernosi and the bulbocavernosus muscles, which are provided with transversely striped fibres, increase the rigidity in the anterior parts by the compression of the root of the penis with the dorsal veins; but under no circumstances can these muscles, of themselves alone, contribute to the bringing about of the erection.

The *investigation* of the male sexual organs does not, in general, present any great difficulties. The seminal tubules are extremely easy to isolate, and when they are teased out with a little care, some of their divisions are always met with. In order to see their course, they must be injected in the method pointed out by *Lauth* or *A. Cooper*, which will be found quoted in all Handbooks of Anatomy. The vas deferens is best studied in transverse sections of preparations which have been hardened or dried, and the same applies to the glands of the prostate; whilst, on the other hand, the muscular structure of the prostate and of the corpora cavernosa can be distinctly made out only when the parts are fresh, or after the employment of nitric acid. The arteriæ helicinæ are recognisable, even in fresh preparations, in the neighbourhood of the large arterial trunks, and still better after injection with fine size.

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B. FEMALE SEXUAL ORGANS.

§ 202. The female sexual organs consist, 1. of the *ovaries*—two follicular glands for the formation of the ova—together with certain bodies named the appendages to the ovary, or *par-ovaria*; and of the two *Fallopian tubes*, which serve as the excretory ducts of the glands, although they are not directly connected with them; 2. of the *uterus*, for the lodgment and nourishment of the embryo; and 3. of the vagina and external genital organs, which serve for the passage of the fœtus in parturition, as well as for sexual intercourse.

§ 203. *Ovary, Appendage to Ovary.*—The ovaries, *ovaria*, are composed of special envelopes and a stroma or parenchyma, containing the ova. The envelopes consist of a peritoneal covering, which invests the whole of the organ, except the lower border, and of a firm, white, fibrous coat, *tunica albuginea s. propria*. This coat is ¼‴ in thickness, and firmly encloses the whole parenchyma, with which it is intimately connected. Although not sharply defined from the stroma, it does not send inwards any processes into its substance, and, in this respect, differs from the corresponding tunic of the testicle, with which, in regard of structure, it exactly corresponds. The stroma is a dense fibrous substance, of a reddish-grey colour, and moderately firm. It is formed of nucleated connective tissue, in which the fibrillæ are but indistinctly visible, and this supports the Graafian follicles and the vessels. At the lower border of the ovary, where the vessels enter, and where Graafian follicles are never situated, it forms a compact lamella, which extends into the interior of the organ, and radiates hence towards

Fig. 183.

Transverse section of the ovary of a female, who died in the fifth month of pregnancy. *a.* Graafian follicles of the lower surface; *b.* the same of the upper surface; *c.* peritoneal lamella of the lig. latum, continuing upon the ovary, and blending, with *d.*, its tunica albuginea; *e.* stroma of the ovary. In the interior are seen two *corpora albicantia* (the remains of corpora lutea).

the two surfaces and the free border of the organ, so that a pencilliform figure appears on a transverse section. The ovi-capsules, or ovi-sacs, usually called Graafian vesicles (*folliculi ovarii s. f. Graafiani s. ovi-sacci*), are little round sacs, ¼‴ to 3‴ in average size, and closed on all sides (fig. 183, *a b*). They are imbedded in the more peripheral parts of the stroma, so that a section of the parenchyma of a well-developed and normal ovary may be described as dividing into a medullary and cortical substance, the latter alone containing the follicles. We must be careful to obtain healthy and well-developed ovaries, if we would obtain a correct view of the size, position, and number of the Graafian follicles. Their number will be found to amount from 30, 50 to 100 in each ovary, and may, in many cases, reach up to 200; while in stunted or degenerated ovaries, such as are frequently seen especially in old women, we may meet with but few (between two and ten, for example), or there may even be none at all.

In its fully-developed condition, each follicle consists of coverings and contents. The former can be compared most suitably to a mucous membrane, and presents the following elements: 1. The *tunica fibrosa*, or *theca folliculi* of *v. Baer*, a fibro-vascular layer of considerable relative thickness, which is connected with the stroma of the ovary by somewhat loose tissue, and, consequently, is easily separable as a whole. The outer layer of this membrane, which is somewhat firmer, and reddish-white in colour (fig. 184, *a*), is distinguished by *v. Baer* from the inner lamina, which is thicker, softer, and more distinctly red in hue (fig. 184, *b*); but, it is to be remarked, that the inner layer also can be split into two parts, and that both the outer and the inner laminæ consist of the same nucleated connective tissue, undeveloped and interspersed with numerous, mostly fusiform, formative cells. A delicate structureless membrana propria forms the inner boundary of the fibrous tunic in young follicles, and even, subsequently, can often be demonstrated as a special membrane, by the action of alkalies. 2. An epithelium — the granular layer, or *membrana granulosa* of authors (fig. 184, *c*). This membrane is 0·008‴ to 0·012‴ and upwards in thickness, lines the whole follicle; on the side turned towards the surface of the ovary,

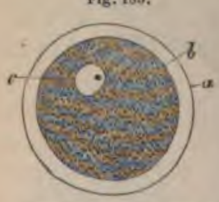
Fig. 184.

Graafian follicle of the pig; magnified about 10 times. *a.* Outer, *b.* inner, layer of the fibrous coat of the follicle; *c.* membrana granulosa; *d.* liquor folliculi; *e.* germinal eminence, a projection of the membrana granulosa; *f.* ovum, with zona pellucida, yelk, and germinal vesicle.

where the ovum is situated, the granular layer presents a papilliform thickening, projecting inwards, around the ovum, for $\frac{1}{3}'''$ in breadth, and named the germinal eminence, or *cumulus proligerus* (fig. 184, *e*). The roundish, polygonal cells of this epithelial layer are 0·003‴ to 0·004‴ in size, and are arranged in several layers; they are furnished with rather large nuclei, and frequently contain some yellowish fat-granules. These cells are extremely delicate, and become indistinct soon after death, so that then the whole epithelium appears only as a finely-granular membrane, with numerous nuclei. In the interior of the follicle there is a clear, slightly yellowish fluid — *liquor folliculi* — of the nature of the blood-serum; this almost always contains separate granules, nuclei, and cells, that can scarcely be anything else than detached parts of the membrana granulosa, and have not had their origin in the fluid itself.

In the germinal eminence, near to the fibrous tissue of the follicle, and, consequently, in the most projecting part of it, lies the *ovum*, or *ovulum*, imbedded in the cells of which the eminence is composed, and firmly fixed by them. When the follicle bursts, or if it be ruptured, the ovulum passes out, surrounded by the cells of the cumulus and the neighbouring parts of the epithelium, which embrace it after the manner of a ring or disc (the *discus proligerus*, or germinal disc, *v. Baer*). This so-called disc, however, is not only placed so as to encircle the greatest breadth of the ovum, but completely encloses it on all sides. The ovulum itself is a spherical vesicle, measuring, in the mature condition, $\frac{1}{8}'''$ to $\frac{1}{10}'''$, which, though peculiar in some respects, still has the nature and structure of a simple cell. The cell-membrane, or *vitelline membrane*, is of the unusual thickness of 0·004‴ to 0·005‴, and is seen by the microscope to surround the contents, or *yelk* (*vitellus*), as a clear, transparent ring, whence it is also called *zona pellucida*. It is structureless, very elastic and firm, so that it can support a considerable distension without tearing, and, in its chemical characters, it completely agrees with the *membranæ propriæ* (§ 14). The slightly yellowish *yelk*, which, in fresh ovula, completely fills the vitelline membrane, consists of a viscid fluid, with numerous fine pale granules interspersed in it. In mature ovula, some fat-granules are also seen, and in these we discover a beautiful vesicular nucleus, placed on one side of the

Fig. 185.



Human ovulum, from a middle sized follicle; magnified 250 times. *a*. Vitelline membrane (zona pellucida); *b*. outer limit of the yelk, and, at the same time, boundary of the vitelline membrane; *c*. germinal vesicle, with the germinal spot.

cell, and measuring 0·02‴ in diameter. The contents of this nucleus are pellucid, and it has a homogeneous, round, parietal nucleolus, measuring 0·003‴ in diameter. The nucleus is termed the germinal vesicle, *vesicula germinativa* (the 'vesicle of *Purkinje*'), and the nucleolus has the name of the germinal spot, *macula germinativa* (or the 'spot of *Wagner*').

The appendage to the ovary, or par-ovarium (*Nebeneierstock*), is a rudiment of the Wolffian body of the embryo, and consists of a certain number of canals, 0·15‴ to 0·2‴ in diameter, diverging from the hilus of the ovary, and passing into the broad ligament of the uterus. In the human subject, these canals do not open into the ovary, nor are they connected with any other parts, and they contain nothing but a small quantity of clear fluid. They consist of a fibrous coat, 0·020‴ to 0·024‴ in thickness, lined by a simple layer of pale cylindrical cells, probably provided with cilia; they are of interest only as being the remains of an embryonic structure.

The *arteries* of the ovary are derived from the spermatic and uterine arteries, and pass upwards into the ovary between the two laminæ of the broad ligament. They appear as numerous small trunks, which run onwards, in a tortuous manner, in the internal parts of the stroma, and terminate, partly in the stroma itself, and partly in the tunica albuginea. They are more especially distributed in the walls of the Graafian follicles, where they form an outer, coarser network, and an inner one with finer meshes; and this reaches as far as the membrana granulosa.—The *veins* arise at the same places, being, in the human ovary, generally very distinctly visible in the walls of the larger follicles, and terminate in the uterine and internal spermatic veins.—Some lymphatic trunks pass out at the hilus of the ovary, and proceed with the blood-vessels to the lumbar and pelvic glands. With regard to the *nerves*, they arise from the spermatic plexus, enter the ovary, with the arteries, as small trunklets, with fine nerve tubules and 'fibres of *Remak*,' but they have not yet been investigated with regard to their ultimate distribution.

My opinion, that the canals of the parovarium have cilia on their epithelium, was based (*Micros. Anat.*, ii. 2, p. 446) on the observation of cilia in cysts of the broad ligament. *Becker*, however, now confirms this view by direct observation. In certain cysts, which were present in large numbers on the ovary of a mare, this author also found ciliated epithelium. In the ova of the rabbit, *Remak* has noticed a fine radiating striated structure in the zona pellucida, which is probably to be ascribed to minute pore-canals.

§ 204. *Detachment and Re-formation of the Ovula.— Corpora Lutea.*—From the commencement of puberty onwards to the period of involution, there takes place in the ovaries a continual detachment of the ovula by the dehiscence of the Graafian follicles; and this occurs equally in married women and virgins, independently of sexual intercourse. It takes place especially at the menstrual period, although, under circumstances not yet accurately ascertained, it may, and frequently does, occur at other times. In animals, the same process presents itself at the period of 'heat,' but here sexual union appears to be a more necessary condition for its completion; here, also, the anatomical changes can be traced in great perfection, whilst, in the human female, the opportunity of making such observations is much more seldom presented.

When the Graafian follicles approach the period of bursting, they gradually enlarge until they acquire a circumference of 4 to 6 lines and upwards, and they come nearer and nearer to the surface, until at last they project beyond it in a wart-like or hemispherical form, being only covered by a thin pellicle of the extremely attenuated tunica albuginea, with its peritoneal covering. At the same time, their vessels increase to an unusual degree, and, by continual exudation from them, the liquor folliculi becomes more and more abundant; meanwhile, the fibrous coat of the follicle, at the bottom and lateral aspect, but not where the ovulum is situated, becomes thickened internally, and the membrana granulosa also swells somewhat, and possesses larger cells (measuring up to 0·01‴ in diameter). When these processes have gone on to a certain extent, the thin opposing membranes are no longer able to withstand the continued and increasing pressure from the interior of the follicle; they give way at the thinnest and most prominent point, exactly where the ovulum is situated. The Fallopian tube, then, applying itself directly over the follicle, receives the ovule on its escape, surrounded by the cells of the germinal eminence. The Graafian follicle, however, has not at this stage completed its career, for it becomes the seat of a series of formations, partly new, in consequence of which it becomes converted into the so-called corpus luteum, and ultimately disappears altogether.

These *yellow bodies* (*corpora lutea*) are best marked when conception and pregnancy follow upon the detachment of the ovulum, and in their most developed condition, they appear as roundish, or oblong firm bodies, generally of larger size than the previous follicles. As a rule, they are visible externally as prominences, and exhibit, on the summit, a stellate cicatrix, arising from the opening of the Graafian follicle. Their outermost limit from the stroma of the ovary is formed by a thin, whitish, fibrous coat (fig. 186, 2 *f*), then follows a yellowish vascular layer, much plicated, and hence having the appearance of considerable thickness (fig. 186, *c*); and in the interior we find a cavity of various size (fig. 186, *d e*), filled either with coagulated blood, or else with a somewhat gelatinous fluid tinged with blood. With regard to the origin of these bodies, it is easy to see that the central part of them consists of the blood which has been effused during the rupture of the follicle, with or without an admixture with the remains of the liquor folliculi; and that the outer fibrous coat is the outer lamina of the original fibrous coat of the follicle. With respect to the yellow, plicated cortical layer, it belongs, for the most part, to the inner lamina of the fibrous coat of the original follicle, which, before the escape of an ovulum, becomes loose and spongy, and afterwards becomes rapidly thickened, measuring as much as $\frac{1}{4}'''$ to $\frac{1}{2}'''$, or even more. This growth is accompanied by the formation of a large number of various-sized cells, which partly become transformed into an imperfect connective tissue and into vessels; while another part of them continues in the state of cells, which are then characterised by their beautiful vesicular nuclei, measuring up to 0·01''' to 0·02''' in size, with nucleoli and a variable number of yellow fat-globules in the interior. The yellow body, having the structure here described, continues of its original size for some time, until the second or third month of pregnancy; but during this period, its central part or nucleus (no matter whether it be a blood-coagulum, or a reddish gelatine with a small cavity) gradually decreases in size, and becomes decolorised, while the yellow cortical layer becomes thicker and thicker. At the same time, the tissue of the corpus luteum becomes more compact and further organised, by the conversion of its inner substance into fibrous tissue, and by the coalescence therewith of the yellow cortical part, in which, meanwhile, more and more young connective tissue is being formed. The atrophy of the yellow body commences in the fourth and fifth months of pregnancy, and advances slowly till the period of gestation, so that in those who have died in childbed it measures 4 lines on an average; afterwards it diminishes more rapidly, until, after some months, the metamorphosed Graafian follicle has entirely disappeared, or has become a *minute, variously coloured* corpuscle, which may persist for a *long period, and, perhaps,* disappear completely, only after a series of years.—Such stunted yellow bodies (constituting the *corpora albicantia* and *nigra*, of authors) are at first definite in outline, and have a dentated nucleus (which rarely possesses a cavity) of a greyish-white or reddish colour, sometimes brown or even black from altered hæmatine. Their cortex presents various shades of yellow, yellowish-white, or even perfect white, and is frequently distinctly folded. Subsequently, however, the so-called corpora albicantia become transformed into irregular spots, whose borders have coalesced with the stroma of the ovary. Their elements consist of fibres of a more embryonic character, such as form the stroma of the ovary; next, of various pigment molecules and coloured crystals (hæmatoidine, *myelin* of *Virchow*); and, thirdly, of white and yellow fat, which exists in the cortical substance, at first in large cells, round, elongated, or fusiform in shape, but ultimately becomes free by the disintegration of the cells, and at length undergoes absorption more or less completely.

Fig. 186.

Sections of two *corpora lutea* of natural size. 1. quite recent, eight days after conception; 2. from the fifth month of pregnancy. *a.* tunica albuginea of the ovary; *b.* stroma of the ovary; *c.* thickened and plaited fibrous coat of the follicle (inner layer); *d.* blood-coagulum; and *e.* decolorised blood-coagulum within the preceding; *f.* fibrous envelope which limits the corpus luteum.

In those yellow bodies, which are formed at a period other than during a pregnancy, the processes are essentially the same as in the others, but the several steps follow each other with much greater quickness, so that these bodies, as a rule, disappear completely, or almost completely, in the course of one or two months, and on this account they never possess the peculiar structure of the bodies formed during pregnancy, which have thus received the name of *true corpora lutea.*

The numerous follicles, which are continually disappearing from the ovaries during the whole prime of life, are replaced, even in the adult, by the continual production of ovi-capsules, which become developed into Graafian follicles. In animals, these new formations, that are met with at the period of heat, are very numerous. They were first observed here by *Barry*, *Bischoff*, and *Steinlin*, and are extremely easy of observation. But in women, no opportunity has presented itself of observing their reproduction; and it is only from the circumstance, that in the normal human ovary also, follicles of the most various sizes are always found, that we can assert that there goes on a continual formation of them. In the human female, the period of conception and menstruation is probably the time for the production of these follicles. Their histological development has been studied in animals, and appears to agree exactly with the mode of origin, presently to be described, of the primitive follicles of the embryo.

§ 205. *Fallopian Tubes and Uterus.*—Of the three coats of the Fallopian tubes, the outermost, belonging to the peritoneum, presents nothing worthy of remark. The middle or smooth muscular coat is moderately thick, especially at the internal half of the tube, and consists of external longitudinal, and internal circular fibres. The innermost coat is the mucous membrane, a thin, soft, reddish-white layer, which is connected with the muscular coat by a small quantity of submucous tissue; it presents no glands or villi, but some longitudinal folds, and consists of immature connective tissue, with numerous fusiform formative cells. From the uterus to the free border of the fimbriæ, there is situated upon its inner surface a simple layer of ciliated cells, conical or filiform, 0·006‴ to 0·01‴ in diameter; these cilia, which are very distinct, produce a current with a direction from the *ostium abdominale* to the *ostium uterinum*, and are probably concerned in the onward movement of the ovula, but not of the semen.

The *uterus* has the same composition as the Fallopian tube, only the muscular and mucous coats are much thicker, and in some respects differently arranged. The muscular coat, of a pale reddish colour, may be best described as consisting of three layers; but these are not sharply defined from each other, as in the muscular strata of the intestines and other parts. The *outer layer* consists of longitudinal and transverse fibres, the former of which extends as a continuous thin layer intimately connected with the peritoneal coat, over the fundus and the anterior and posterior surfaces, as far as the cervix, whilst the thicker transverse fibres pass round the organ, and are partly continued beyond the uterus into the round and broad ligaments, the ligament of the ovary, and upon the Fallopian tubes. The *middle layer* is the thickest, and is formed of flat fasciculi, running transversely, longitudinally, and obliquely, and variously interwoven through each other. This layer contains large vessels, especially veins; and hence, in the pregnant uterus more especially, it exhibits a spongy appearance. The *innermost layer*, lastly, is again thinner, and is formed by a network of fibres, some thin and longitudinal, others thick, and passing in directions transverse and oblique; and these often present very distinct rings at the openings of the Fallopian tubes. In the fundus, where the uterus possesses the greatest thickness, the middle layer is thickest, and is composed as it were of several laminæ, whilst at the cervix, where the organ is thinner, transverse fibres, intermingled with scattered longitudinal ones, are chiefly to be met with. Towards the external *os uteri*, and around this aperture, are situated very well developed circular fibres, immediately beneath the mucous membrane, and these may be designated the *sphincter uteri*.—With reference to these elements, all these layers consist of short (0·02‴ to 0·03‴ in length) fusiform fibre-cells, with oval nuclei arranged longitudinally: these can only be isolated with difficulty, on account of the large quantity of nucleated connective tissue of embryonic characters which passes between them; even on the employment of nitric acid of 20 per cent., these fibre-cells do not come so distinctly to view as in other places.

The *mucous membrane* of the *uterus* is a white or reddish-white membrane, which is firmly connected with the muscular coat, and cannot be dissected away from it; upon section, however, it is distinguished from it, although not sharply, by its brighter colour. In its basement layer and its epithelium, this membrane has the same structure everywhere in the uterus; the former consisting of that connective tissue which is seen throughout the female genital organs, containing undeveloped nuclei and fibre-cells, but no elastic elements; the epithelium being throughout a simple layer of the ciliated variety, with pale cells, measuring up to 0·01‴ in diameter, and delicate cilia which produce a current from without inwards. In other respects, however, the mucous membrane of the uterus exhibits a different structure in the body, fundus and cervical canal. At the former place it is thinner and more delicate, measuring only from half a line to a line, and has a more reddish colour. Its inner surface is here smooth and without papillæ, but occasionally presents some large folds. Here are found very many small glands, the tubular glands of the uterus, named also the *uterine glands* (*glandulæ utriculares s. uterinæ*), which possess the greatest resemblance to the glands of *Lieberkühn* in the intestine, and are simple or furcated tubes, arranged closely together, of the same length as the thickness of the mucous membrane, and 0·02‴ to 0·03‴ in breadth; they are not unfrequently twisted spirally at their extremities. They consist of a very delicate structureless coat, lined by a regular cylindrical epithelium, and they open to the surface of the mucous membrane, either singly or in groups of twos or threes together, with apertures 1/[illegible]‴

in diameter. In their normal condition, these glands contain no morphological particles; but their epithelium is very easily detached, and may appear as a whitish-gray secretion filling them. These glands have been observed by *H. Müller* in persons seventy to eighty years of age, as well as in a child of two years old; in diseases, however, they are very readily destroyed.

In the cervix, the mucous membrane is whiter, firmer and thicker than in the body; it averages 1‴ to $1\frac{1}{2}$‴ in thickness, and is especially thick on the anterior and posterior wall: here the well-known *plicæ palmatæ* are found, and lying between them we meet with sinuous depressions of various sizes, a line and more in depth, and lined by cylindrical epithelium. These pits or depressions differ, indeed, very essentially from the ordinary mucous glands, yet, as the organs which secrete the viscid clear mucus of the cervix uteri, they may be distinguished by the name of the *mucous follicles* of the uterus. In this region also, there are frequently found short vesicles, $\frac{1}{3}$‴, 1‴ to 2‴ and more in diameter, filled with a similar mucous secretion, and composed of a layer of connective tissue, with short cylindrical cells. These are the so-called *ovula Nabothi*, which are nothing but enlarged mucous follicles, whose apertures are closed, whilst others of them are pathological new formations; they are occasionally found also in the mucous membrane of the body of the uterus. The lower third or the lower half of the cervix contains wart-shaped filiform papillæ, 0·1‴ to 0·3‴ in length, covered with ciliated cylindrical epithelium; together with one or more vascular loops in their interior, numerous small nuclei and pale fat-globules are seen in them.

The distribution of the vessels in the non-pregnant uterus, does not present much that is peculiar. The larger arterial branches run in the muscular substance, and are distributed thence in the various muscular layers, and the mucous membrane of both sides of the organs. The vessels of the mucous membrane are, as usual, larger in the deep portions, and finer in the more superficial. The fine arterial twigs of the latter, after they have surrounded the glands with fine capillaries, form an extremely rich and beautiful network of coarser capillaries (0·006‴ to 0·01‴) on the surface, from which the veins arise; these are wide, thin-walled, and unprovided with valves, and resemble the arteries in their passage outwards. The lymphatics, which probably commence in the mucous membrane, are extremely numerous, form coarser and finer networks beneath the peritoneal covering, and lead partly to the pelvic glands by means of numerous large trunks accompanying the blood-vessels, partly to the lumbar plexus in company with the spermatic vein. The nerves of the uterus, which contain many fine nerve-tubes, and a few isolated thick ones, come from the *plexus hypogastrici* and *pudendi,* and pass to the uterus from the broad ligament, in which they form a plexus; they generally follow the course of the vessels, and ramify in the muscular substance from the fundus to the cervix, at which latter place they are most numerous. They are white, and possess no ganglia in the substance of the uterus; their arrangement and termination in the mucous membrane are unknown.

Of the ligaments of the uterus, the *ligamenta lata, anteriora* and *posteriora,* are duplicatures of the peritoneum, which, besides the afferent and efferent vessels and nerves, contain a considerable number of smooth muscular fibres, continuous with those of the uterus. The same tissue, likewise coming from the uterus, is found sparingly in the *ligamenta ovarii,* and in very considerable quantity in the round ligaments, where it forms longitudinal bundles surrounded by connective tissue. At the internal inguinal ring, these fibres are joined by numerous others of the transversely striated kind, which often extend along the round ligament nearly to the uterus.

The Fallopian tube has occasionally two or even three *ostia abdominalia. G. Richard,* who first pointed out these anomalies (*Anat. des Trompes de l'Uterus, Thèse,* Paris, 1851) has met with them five times in thirty cases examined by him, and he has also seen blind accessory *ostia* furnished with fimbriæ. Similar cases have recently been described by *W. Merkel* (*Beit. z. path. Entw. d. Genit.* Erl., 1856, Diss).

§ 206. *Changes of the Uterus at the Period of Menstruation and Pregnancy.*—During the period of the menses, the whole uterus enlarges and becomes looser in texture. This appears to result, however, rather from the dilatation of the vessels, and the great infiltration of the entire organ with blood-plasma, than from any other alteration in the elements of the muscular substance: at any rate, I have witnessed no other change in them, except that they were easier of demonstration. On the other hand, the mucous membrane, in many cases, really does increase; it becomes softer and thickened to 1‴, 2‴ to 3‴, and in its projecting folds even up to 5‴ or 6‴: it presents also at this time, beautiful easily separable tubular glands, 1‴ to 3‴ in length and 0·036‴ to 0·04‴ in breadth, and in the tissue of the mucous membrane are found numerous young cells, round and fusiform in shape. The blood-vessels of the mucous membrane, from which the menstrual fluid is chiefly derived, are now extremely numerous, and are enlarged over the entire circumference of the uterus, especially in the fundus and body; this enlargement especially affects the superficial network, on which account the mucous membrane appears of a bright red colour. With the effusion of the blood consequent on the rupture of the superficial capillaries, the epithelial lining of the body and fundus is for the most part also thrown off, and its cells are always found in large quantities, mixed with the blood and mucus which fill the cavity of the uterus; on the other hand, we are not to regard as a normal process the detachment of the mucous membrane, as a whole or in fragments, which sometimes occurs after or during the catamenia. After the menses, the parts quickly return to their previous condition, and the epithelium is formed anew.

Of an entirely different character are the changes which are produced in the uterus by pregnancy; among these, however, in a microscopical point of view, only the increase of the organ is of interest. This enlargement, as is well known, depends upon an enormous increase in the circumference and in the cavity of the organ, and upon an increase in substance amounting on an average (*J. F. Meckel*) to twenty-four times the original bulk; the thickness of the walls is at first increased, but it afterwards diminishes, usually from the fifth month of pregnancy onwards. The chief seat of the changes by which the increase in volume is effected, is in the muscular substance of the uterus. Here there are two processes which operate together to effect this increase; first an enlargement of the muscular elements already existing, and secondly, a new formation of similar elements. The former method is so considerable, that the contractile fibre-cells, instead of being 0·02‴ to 0·03‴ in length, and 0·002‴ in breadth, as at other times, measure at the fifth month of pregnancy, 0·06‴ to 0·12‴ in length, 0·0025‴ to 0·006‴, or even 0·01‴ in breadth: in the latter half of the sixth month, they measure 0·1‴ to 0·25‴ in length, 0·004‴ to 0·006‴ in breadth, 0·002‴ to 0·0028‴ in thickness; so that they increase between seven and eleven times in length, and between two and five times in breadth. The new formation of muscular fibres is especially to be observed at the beginning of pregnancy in the innermost layers of the muscular coat, where newly formed round cells, 0·01‴ to 0·018‴ in diameter, are found in large quantities and in all states of transition into fibre-cells of 0·02‴ to 0·03‴ in length; this process, however, is not absent even in the outer layers. From the sixth month onwards, the mode of development of muscular fibres appears to cease; at least, in the twenty-sixth week I have found *nothing but colossal fibre-cells* in the whole uterus, and no trace of earlier forms. Like the muscular fibres themselves, the fibrous tissue which unites them also increases, and presents here and there, towards the end of pregnancy, distinct fibrillæ.

Fig. 187.

Muscular elements from the pregnant uterus. *a*, formative cells of the muscular fibres; *b*, advancing, and *c*, developed, fibre-cell. The above are from the uterus at the fifth month: the remaining figures are from the six months' pregnant organ. *a*. Muscular fibre-cell from a six months' pregnant uterus; *b*. the middle part of the same after treatment with acetic acid, presenting the semblance of an envelope; *c*. nucleus of the fibre-cell.

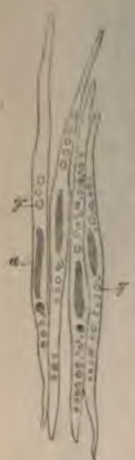
Whilst the muscular coat is growing in this manner, the mucous membrane is also undergoing alterations of various kinds. It is the mucous membrane especially which is the seat of the earliest metamorphoses of the gravid uterus, for as early as the second week, it thickens to two or three lines, becomes softer, looser and redder, acquires more prominent folds, and becomes more distinctly marked off from the muscular coat; these peculiarities are more and more distinct as the pregnancy is farther advanced. Microscopically examined, the vessels of the mucous membrane are seen to be more dilated, and we may observe an abundant new formation of connective tissue in its parenchyma, while considerable enlargement of the tubular glands has also taken place; these latter now measuring two or three lines in length, and 0·04‴ to 0·11‴ (0·08‴ on an average) in breadth. In the further course of the changes, the greater part of the hypertrophied mucous membrane goes to form the well-known *decidua vera*, whilst another portion at the point of attachment of the ovulum is transformed into the *placenta uterina*, the decidua reflexa arising around the ovulum by a growth from the border of this last-mentioned portion. These processes, however, we will not further discuss in this place. Two or three points it may be well to remark:—Firstly, that the uterine glands in the *decidua vera* are gradually converted into wide saccules, whose openings give a cribriform appearance to it, and to the border of the *reflexa*. Another point to be noted is, that the deciduæ gradually decrease in thickness from the second month onwards, although in actual bulk they continue to increase for a much longer period, in consequence of the enlargement of the inner surface of the uterus. Lastly, we may observe, that the tissue of the decidua always consists of round cells of various size, with one or more very conspicuous nuclei; along with these, we find colossal fibre-cells with beautiful large nuclei, and also numerous vessels, especially in the decidua vera: on the other hand, after the first month, there is no longer any epithelium to be found on either decidua.—The mucous membrane of the cervix takes no part in the formation of the decidua, and retains its epithelium (which has no cilia) during the whole period of pregnancy. Yet it likewise swells up and becomes enlarged, its mucous follicles more especially, which secrete the well-known plugs of mucus that complete the occlusion of the canal of the cervix.

Fig. 188.

A uterine gland from a primipara, eight days after conception.

In the course of pregnancy, the serous covering to the uterus distinctly increases in thickness, but not to the same degree as the mucous membrane; on the other hand, the thickening of the uterine ligaments, especially of the *lig. rotundum*, is very distinct; and this depends upon changes of their smooth muscular fibres, similar to those which have been described as occurring in the uterus; perhaps, also, the thickening may in part depend upon an increase of the transversely striped fasciculi. The growth of the blood-vessels and lymphatics in length and circumference is likewise evident, and this, too, is in great measure to be attributed to enlargement and new development of muscular elements, which in the veins can be demonstrated both in their *tunica adventitia* and *tunica intima*. With regard to the nerves, they likewise become thickened, yet it is doubtful whether new nerve-tubes really arise in them. It is certain, however, that the existing elements increase in breadth and length, retain their dark-bordered contours, and can be traced further into the substance of the organ than at other times.

Fig. 189.



Muscular fibre-cells of the uterus, three weeks after parturition; of a pale appearance, from being treated with acetic acid. a. their nuclei; γ. fat-granules in their interior. Magnified 350 times.

The diminution of the uterus after parturition, and the re-establishment of a condition resembling though not identical with that which preceded conception, takes place in the several parts of the organ in a slightly different manner. In the muscular coat, an atrophy of the contractile fibre-cells is obviously the chief means of reduction, inasmuch as, three weeks after birth, these elements again present the same length (0·03‴) as in the virgin uterus, while a formation of fat is going on in their interior: still, however, a complete absorption of certain muscular fibres may be superadded to this. The case is different with the mucous membrane, which is completely thrown off after parturition in the form of the *deciduæ* and *placenta uterina*, and thus has to be entirely formed anew. The more intimate processes of their regeneration, which is unique in its kind, have not yet been followed, still it is more than probable, that it is completed within the first two or three months after child-birth. It is obvious, also, that the serous coat, and the vessels and nerves of the uterus, enter into a retrogressive metamorphosis, though the particulars of this change have not yet been investigated.

§ 207. *Vagina and External Parts of Generation.*—The walls of the vagina, one line in thickness, consist of an external fibrous coat, a middle muscular layer and a mucous membrane. The fibrous coat, thin and whitish, consists of a connective tissue, with numerous elastic fibres and networks of veins; externally it is more lax, but it is denser at its internal aspect where it passes without any line of demarcation into the second coat. This stratum has a redder colour than the outer coat, and contains connective tissue and numerous veins, together with a considerable number of well developed smooth muscular fibres, which are particularly well seen during pregnancy. The fibre-cells, 0·04‴ to 0·08‴ in length, are arranged in transverse and longitudinal fasciculi, and constitute a true muscular coat. The mucous membrane is of a pale reddish colour, is studded with numerous folds and eminences of variable size—the *columnae rugarum*—and is composed of a dense connective tissue without glands, which possesses elastic elements in large quantity, and is consequently remarkable for its great firmness and extensibility. The inner surface of this mucous membrane exhibits numerous filiform and conical papillæ, 0·06‴ to 0·08‴ in length, and 0·025‴ to 0·03‴ in breadth, which are completely imbedded in a pavement epithelium 0·07‴ to 0·09‴ thick, of the same kind as in the œsophagus; the uppermost cells, which are flattened, measure 0·01‴ to 0·015‴ in diameter, and contain nuclei 0·003‴ in diameter. The hymen is a duplicature of the vaginal mucous membrane, and possesses the same elements.

From the vagina, the mucous membrane also extends upon the external genitals, covers the glans clitoridis and the vestibule with the opening of the urethra, while folds of it form the *preputium clitoridis* and the *labia minora*. At the *labia majora*, it passes uninterruptedly into the external integument: on their inner side, and at the commissure, the integument of the greater labia presents more the characters of a mucous membrane, whilst at their borders, on their outer surface, and on the *mons veneris*, it completely resembles the cutis. The fundamental portion of the mucous membrane of the external genitals, consists of a loose connective tissue, with numerous fine elastic fibres and free from fat, in which numerous vessels ramify. The condensed outer layer of this membrane ($\frac{1}{4}$‴ to $\frac{1}{5}$‴ thick), corresponding to the corium, possesses everywhere very well developed papillæ (measuring in the labia minora, $\frac{1}{10}$‴ to $\frac{1}{20}$‴, on the clitoris, $\frac{1}{24}$‴ to $\frac{1}{33}$‴ in length), and a lamellated pavement epithelium, 0·04‴ to 0·12‴ in thickness, whose most superficial cells measure 0·01‴ to 0·02‴ in diameter (fig. 40, 4). The integuments covering the *labia majora* agree in their structure partly with the mucous membrane, partly with the cutis; and these parts contain ordinary adipose tissue in their interior.

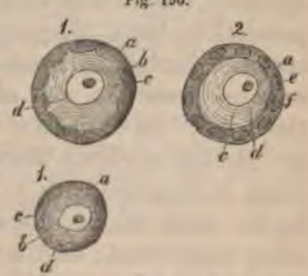
The external genital organs are provided with various glands, some larger and some smaller. *Sebaceous glands* of considerable size ($\frac{1}{4}$‴ to 1‴), and usually of a moniliform shape, are found upon the *labia majora*, both on their external and on their internal aspects, in connection with larger and smaller hair-follicles; more internally, similar glands are found in large numbers on the *labia minora;* here they are somewhat smaller ($\frac{1}{10}$‴ to $\frac{1}{6}$‴), and are generally independent of hairs; lastly, these glands are *occasionally observed* around the opening of the urethra, and on either side at the entrance of the vagina. Next we meet with mucous glands, having the ordinary structure of racemose glands, which measure $\frac{1}{3}'''$ to $1\frac{1}{2}'''$ in diameter, and are provided with short excretory ducts (sometimes, however, these are six lines long), opening to the surface by orifices, which are sometimes of good size, sometimes very difficult of detection. These glands are found in very variable number around the aperture of the urethra, the vestibule, and the sides of the entrance of the vagina. Lastly, there are met with at the lower end of the bulbs of the vestibule, laterally at the entrance of the vagina, the two glands of *Bartholini*, which correspond to the glands of *Cowper* in the male; they are ordinary racemose mucous glands, half an inch in diameter, with pyriform gland vesicles (0·02''' to 0·05''' in diameter), lined by a pavement epithelium, and imbedded in compact connective tissue, containing nuclei, but destitute of muscular fibres. The excretory ducts of these glands, seven to eight lines long, half a line broad, have a mucous membrane lined by cylindrical epithelial cells, 0·01''' in size, and external to this a delicate longitudinal layer of smooth muscular fibres; the ducts always contain a viscid amorphous mucus, transparent, and of a yellowish colour.

The clitoris with its two corpora cavernosa, and the glans connected with the bulbi vestibuli—which represent in the female the two separate halves of the spongy tissue of the male urethra—present in miniature the same structure as the corresponding parts in the other sex; the muscular elements can here be more easily isolated than in the male organ.

The blood-vessels of the vagina and of the external genital organs, present on the whole but little subject for remark. In the papillæ of the different parts, we generally find simple vascular loops, and only when these papillæ are larger or compound, as is frequently the case around the aperture of the urethra, do we meet with several loops of vessels in their interior. The corpora cavernosa present the same arrangement of their vessels as in the male, and according to *Valentin*, *arteriæ helicinæ* also appear to occur in the clitoris. The venous plexuses in the walls of the vagina above the bulbs of the vestibule, are exceedingly abundant, yet they by no means represent true cavernous bodies, as *Kobelt* supposed. The lymphatics of the external genitals and of the vagina are numerous, and open partly into the inguinal glands, partly into the pelvic plexus. The nerves, lastly, arise partly from the sympathetic, partly from the *plexus pudendus*, and are extremely numerous, especially in the clitoris, though they are not difficult to find even in the vaginal mucous membrane. In the latter situation they are seen to divide, but their terminations have hitherto been but little investigated. I have never found nerves in the vascular papillæ; on the other hand, I have occasionally observed them in the clitoris in small non-vascular papillæ, which also contained rudimentary tactile corpuscles, and both here and upon the surface of the mucous membrane itself (in which also structures similar to tactile corpuscles may be detected here and there), I have noticed an appearance of loops upon the nerves, both on the finer and the thicker fibres. In the clitoris of the sow, *Dr. Nylander*, of Helsingförs, has discovered Pacinian bodies, which I have also seen; and junctions between the nerve-tubules in the papillæ by means of loops.

§ 208. *Physiological Remarks.*—The development of the internal parts of generation in the female, which was already spoken of above (§ 201), completely agrees in its early stages with the process observed in the male; and it is only after some time that the histological development of the sexual glands begins to be different in the two sexes: it is to be remembered, however, that in the female, the Wolffian body, beyond forming the appendage to the ovary, enters into no further relation with the genital organs; whilst the so-called 'ducts of *Müller*' are transformed into the Fallopian tubes, uterus and vagina. With regard to the histological condition of their parts, it is almost only the ovaries which possess any great interest. They consist, at first, of ordinary formative cells, measuring 0·005‴ to 0·009‴, some of which are subsequently transformed into fibres and vessels, while others continue as cells, multiply spontaneously, probably by division, and are subservient to the formation of the Graafian follicles. The latter, according to *Barry*, first present themselves in the form of small groups of cells (each group measuring 0·01‴), which contain in the interior a clear vesicle—the germinal vesicle; these groups, however, soon assume the nature of follicles, by the formation externally of a delicate structureless membrane around the cells, and the cells then assume the characters of an epithelium.

Fig. 190.



Three Graafian follicles from the ovary of a newly-born infant, magnified 350 times. 1, without, 2, with, acetic acid. *a*. structureless coat of the follicle; *b*. epithelium (membrana granulosa); *c*. yelk; *d*. germinal vesicle with spot; *e*. nuclei of the epithelial cells; *f*. vitelline membrane, very delicate.

Such Graafian follicles (ovisacs, *Barry*) are found in thousands in the ovaries of the nearly mature fœtus and of the newly-born infant, and their subsequent development is very easily followed. The follicle grows by the multiplication of the cells of its epithelium (*i.e.* of the membrana granulosa), and at the same time a fibrous vascular envelope is formed upon it from without; meanwhile, a clear substance (in man, having but few granules), collects in the interior, and pushes the germinal vesicle (0·0065‴ to 0·008‴ in diameter), with its germinal spot (0·001‴ to 0·0015‴), from the epithelium, to which it was at first closely applied, into the middle of the follicle. When the Graafian follicle has attained a diameter of 0·02‴, another envelope appears in its interior, enclosing the germinal vesicle and the entire contents of the follicle, and lying closely upon the membrana granulosa. This is the *vitelline membrane*, which all authors regard as a secondary formation, although, perhaps, it is present even in the very earliest rudiment of the follicle, as an extremely fine membrane, closely surrounding the germinal vesicle. At all events, when first traceable, the vitelline membrane is extremely delicate and scarcely perceptible, but subsequently becomes more distinct as the follicle becomes further enlarged and acquires new fluid; for now it gets removed from the wall of the follicle, and shortly also becomes thickened. In follicles of 0·04‴ to 0·05‴ in diameter, the ovula are already perfectly distinct, and are disproportionately large, being surrounded with a delicate zona, and still lying very near to the walls of the follicles. The further development can be easily understood; and I will only remark further, that it is but rare to find follicles visible to the naked eye in newly-born infants; on the other hand, such follicles make their appearance even before puberty, but not until this period do they begin to show themselves conspicuously.

According to what has been said, the mode of origin of the Graafian follicles belongs to the same category as that of the tubular glands. The first commencement is a heap of cells, at first, perhaps, without any cavity or contents, and then arises the structureless membrane, not by the coalescence of the outermost cells, but probably as a secretion from them; thus a follicle is formed, which therefore corresponds in all respects to a shut gland vesicle, or to a portion of a tubular gland canal. It is doubtful whence the germinal vesicle and the vitelline membrane take their origin: the whole ovum, with the germinal vesicle, is probably nothing else than the central cell of the primitive rudiment of the Graafian follicles, and is, therefore, present with the latter from the outset. At any rate, it corresponds to a cell, and the germinal vesicle is nothing but the cell-nucleus; while the thick zona pellucida may be regarded as a secretion from the delicate vitelline membrane in its primitive stage.

The secretions of the female genitals, apart from those of the ovary, are: 1. a whitish mucus in the uterus, which probably comes in the main from the uterine glands, and has an alkaline reaction; 2. a transparent tenacious alkaline mucus in the cervix uteri (see *supra*); 3. an acid mucus in the vagina, which very often contains pus corpuscles, an infusorium, named by *Donné* the *trichomonas vaginalis*, and a fungus, the leptothrix buccalis, *Rob.*; 4. the clear viscid secretion of the Bartholinian glands, which is discharged in large quantity during copulation, and on irritation has been seen to escape even in jets, from the action of the muscular fibres in the ducts; 5. the secretions of the small sebaceous and mucous glands of the external parts.

Investigation of the Female Organs of Generation.—The Graafian follicles are to be examined in as fresh a state as possible, if it be desired to see the membrana granulosa and the ova in their natural conditions. In follicles that have been kept, the epithelial layer swims in flakes in the *liquor folliculi*, and the germinal eminence is generally also destroyed. The position of the ovulum can be recognised in certain animals, as in the bitch, for example, even before the follicle is opened: in order to obtain the ovulum with certainty, a large follicle, which has been carefully dissected out, is to be opened under water, and the larger flakes which escape are to be examined with a low magnifying power; but the ovum may also be readily found when the contents of a follicle are received upon the object-slide of the microscope. One may also be obtained by cutting across or teasing out the ovary, but this is not exactly a method to be recommended. The muscular fibres of the Fallopian tubes, of the uterus, vagina, etc., are to be examined by careful dissection, as also in fine sections of the hardened parts. *Kasper* recommends that the uterus should be boiled for three minutes in water, and then be laid for twenty-four hours in a most concentrated solution of carbonate of potass, or that it should be treated with pyroligneous acid, and the sections moistened with diluted acetic acid; whilst *Schwartz* and *Reichert* dry the uterus which has been hardened in alcohol, and render the muscular fibres distinct by allowing nitric acid of 20 per cent. to act upon them for a short time. The method also which *Wittich* employs in the examination of the kidneys (p. 419) is, according to *Gerlach*, useful in the case of the uterus. The contractile fibre-cells are nowhere to be seen more beautifully than in the pregnant uterus, whilst the uterine glands are best marked in menstruating females, and in the first month after conception. The ciliated epithelium is seen only in perfectly fresh objects, and best of all in the Fallopian tubes; the cells without cilia are easy of observation. The preparation of the external parts presents no difficulties, and the rules which have been previously given, hold good for the glands, nerves, papillæ, and epithelium.

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C. OF THE LACTEAL GLANDS.

§ 209. The *Lacteal Glands (glandulæ lactiferæ)* are two compound racemose glands, which, in the male, are only rudimentary, but in the female are fully developed, and secrete the milk after parturition.

With regard to their structure, the lacteal glands completely agree in all essential points with the larger racemose glands, the parotid and pancreas, for instance. Each gland consists of fifteen to twenty-four and more lobes, whose shape is irregular, flat or cylindrical, roundish or angular, and $\frac{1}{2}'''$ to $1'''$ in size; although quite separate from each other in their cavities, these lobes cannot always be sharply defined externally. Each of them is composed of a certain number of smaller lobules, and those of others still smaller, the smallest lobules being made up of the gland-vesicles. The latter are roundish or pyriform. 0·05‴ to 0·07‴ in size, and are marked off by a distinct constriction from the finest excretory ducts (more decidedly, for example, than in the small mucous glands). Here, as elsewhere, the gland-vesicles are composed of a structureless membrane and a pavement-epithelium; the latter undergoes peculiar metamorphoses at the period of lactation. All the gland-elements are surrounded and united into a compact glandular mass by a dense, white, connective tissue that is very abundant, especially between the acini and smaller lobules; and the whole is covered by a large quantity of adipose tissue, and, on one aspect, by the skin. The lacteal glands are not, properly speaking, simple glands, but, like the lachrymal glands, aggregations of such; that is to say, by the coalescence of the excretory ducts of the smaller and larger lobules, there arises eventually from each lobe a shorter or longer duct, 1 to 2 lines wide, the lacteal duct or canal, *ductus lactiferus s. galactophorus*, which runs separately towards the nipple, always receiving smaller ducts in its course. Beneath the areola, the duct enlarges to an elongated sac, 2 to 4 lines wide, the *sacculus s. sinus lactiferus*, and then, diminished to 1, or even ½ a line in diameter, turns into the nipple, and ultimately opens independently upon its apex by an aperture ⅓‴ to ⅕‴ in width, situated between the little eminences which are here seen. The epithelium, in the thickest ducts, presents cylindrical cells 0·006‴ to 0·01‴ in length; but, in the finer ramifications, on the other hand, smaller cells, roundish or polygonal. Besides this epithelium and a homogeneous layer beneath it, all the excretory ducts possess a white, dense, fibrous coat, which is folded longitudinally in the larger canals; in this I have not hitherto been able to detect undoubted muscular fibres, but only a nucleated, longitudinal, connective tissue, with fine elastic fibres. *Henle*, however (*Jahresberichte*, 1850, p. 41), as also

Fig. 191.

Some of the smallest lobules of the lacteal gland of a puerperal woman, with their ducts; magnified 70 times. After *Langer*.

H. Meckel, believe they have recently observed longitudinal muscular fibres in the lacteal ducts; not in those of the nipple, but deeper in the gland.

The *nipple* and the *areola* possess numerous smooth muscular fibres, to which they owe their contractility (*vide* § 36); a delicate epidermis, whose horny layer, in the female, measures only 0·006''' in thickness, while the Malpighian layer is 0·04''' thick, and coloured in the deeper portions; and compound papillæ, $\frac{1}{10}'''$ to $\frac{1}{33}'''$ in height. On the breast itself, the papillæ of the skin are small ($\frac{1}{60}'''$ to $\frac{1}{80}'''$) and simple, and the epidermis is still thinner (0·032''' to 0·04'''), though the horny layer of it is of greater thickness, measuring 0·02''' to 0·024'''. In the areola, especially at its border, but not on the nipple itself, there occur large sudoriparous glands, often with peculiar contents, and large sebaceous glands, in connection with fine hairs; these glands often form small prominences, visible externally (*vide* §§ 67 and 73). In man, I have observed sebaceous glands upon the nipple also, but without hairs.

The blood-vessels of the lacteal glands are numerous, and surround the gland-vesicles with a pretty close network of capillaries. The veins in the areola form a circle, which is not always quite complete (*circulus venosus Halleri*).—The lymphatics are also very abundant in the skin which covers the gland, but they have not yet been demonstrated in the gland itself.—The nerves of the skin which covers the mamma come from the supra-clavicular nerves, and the cutaneous branches of the second to the fourth intercostal nerves. No nerves can be traced into the interior of the gland, except some fine branches running with the vessels, the termination of which is unknown.

The lacteal gland enlarges very considerably at the period of lactation. Its tissue is no longer uniform, whitish, and firm, but becomes softer, granular, and lobulated, and the reddish-yellow granular parenchyma is distinctly marked off from the lax, whitish, interstitial tissue. The gland-vesicles and lacteal ducts are now wider and filled with milk, while the vessels are greatly increased in number. In the external parts, the enlargement of the areola and nipple is more especially worthy of notice, a phenomenon which seems to depend upon a true growth of these parts with all their elements, including the muscular fibres and the small glands, and not upon a simple distribution of the colour over a larger surface.—In the male, the lacteal gland is quite rudimentary, from half to two inches broad, and 1 to 3 lines thick, firm and without lobules. The lacteal ducts are destitute of the *sinus lactiferi*, and are never so far developed as in the female; they either correspond in form to the ducts which are met with in the glands of newly-born infants, or they will be found in larger specimens of the male gland, to be variously ramified and beset with a certain number of terminal vesicles, which, on account of their considerable size, cannot be regarded as true gland-vesicles or acini. Indeed, according to *Langer*, their size is three times greater than that of the true gland-vesicles in the female, but *Luschka* describes them as only 0·02‴ in width. In rare, but well established cases, the male gland may take on such a development, that it becomes fit for the secretion of milk.

§ 210. *Physiological Remarks.*—The development of the mammary gland follows the same course as the other superficial glands, and, at its first appearance, in the fourth or fifth month, consists of nothing but a solid, papilliform process of the mucous layer of the epidermis, which is enveloped by a layer of dense cuticular tissue (see my researches in *Mitth. d. Zürcher nat. Ges.*, 1850, No. 41). Then, by sending out a certain number of processes, the first rudiments of the subsequent lobes arise in the sixth or seventh month. At their origin, the lobes are nothing but small, pyriform, or flask-shaped processes, proceeding from the common gland-rudiment; but towards the end of fœtal life, these become isolated from each other, and open externally, while, at the same time, they are beginning to give off roundish or elongated solid processes at their closed extremities. At the period of birth, the gland measures 1½ to 4 lines, and exhibits distinctly a certain number of segments, twelve to fifteen in number, the inner of which approach to the still rudimentary nipple, and there terminate, either by a simple flask-shaped neck, or with two or three dilatations; while the outer segments are connected with a greater number of such dilatations. The excretory duct of each of these rudimentary lobules, which is either simple or branched two or three times, is composed of a fibrous coat of immature, nucleated connective tissue, with a small cylindrical epithelium. The ducts are distinctly hollow, while their bulbous ends are still destitute of a cavity, and can no more in this, than in other developing glands, be called terminal vesicles, seeing that they consist of nothing more than small nucleated cells, with the fibrous envelope which passes over them from the ducts. From this very simple form, the subsequent structure is developed by the continual formation of processes from the primitive and subsequently formed bulbous ends; by the excavation of these, which keeps pace with the above process, there arises a highly ramified duct, whose branches are beset with whole groups of hollow gland-vesicles; these stages of development, however, follow each other much more slowly in the mamma than in any other organ of secretion. According to *Langer*, to whom we are indebted for careful observations on the subject, true terminal vesicles never exist before the commencement of puberty, but only imperfectly developed ducts with swollen ends. True gland-vesicles are formed at the commencement of puberty, at first, however, only at the border of the gland, until, at last, the whole gland becomes completely developed with the first pregnancy. After the first lactation, the gland, indeed, diminishes again, but remains persistent in all its parts, and, during subsequent conceptions, simply enlarges, without the addition of new parts. At the period of involution—perhaps, also, when too long a period elapses after a pregnancy without the gland being called into action—it enters into a retrogressive metamorphosis, until at last, in old age, all the gland-vesicles have disappeared, and only the lactral ducts of inconstant width, and with their epithelium in a state of fatty degeneration, are to be found imbedded in the cushion of fat which now occupies the place of the true gland-tissue.

The milk — the secretion of the lactral glands — consists of a fluid portion or plasma, holding in suspension innumerable, round, dark, shining corpuscles, varying in size, from a maximum of 0·0024‴ to 0·0004‴ and upwards, to others which are too small to be measured. These are the milk-globules, which, in all probability, possess a delicate envelope of caseine around the particles of fat, of which they consist; it is to these corpuscles that the milk owes its white colour. With regard to the formation of the milk, it is to be remarked, that at other periods than those of lactation and pregnancy, the glands contain nothing but a small quantity of yellowish viscid mucus, with a certain number of epithelial cells, and are lined to their extremities with a pavement-epithelium, which becomes cylindrical externally. On conception, this structure becomes altered. The cells of the gland-vesicles begin to enlarge and to develop fat in their interior (at first but little, afterwards more and more), so that they completely fill the terminal vesicles. To this is super-

Fig. [illegible]

Morphological elements of the milk; magnified 300 times. a. Milk-globules; b. colostrum corpuscles; c d. cells with fat-globules, from the colostrum, the one d. with a nucleus.

added, before the end of pregnancy, a new formation of cells containing fat, in the gland-vesicles, so that the older cells become forced into the lacteal ducts, and gradually fill them. Thus it happens that, although no proper secretion yet takes place, that some drops of a fluid can, as a rule, be pressed out of the gland in the latter half of the pregnancy. This fluid is not, indeed, real milk, as its yellowish colour will show; but still it contains a certain number of fat-globules, quite similar to the subsequent milk-globules; and these are derived from the fatty cells, more or less disintegrated, and with them entire cells of the same kind are also seen, with or without an envelope; and these are the so-called *colostrum* bodies. When lactation commences after parturition, the formation of cells in the gland-vesicles attains an unusual energy, so that the fluids collected in the lacteal canals and acini are discharged in the first three to four days as *colostrum*, or immature milk, which then gives way to the secretion of the true lacteal fluid.

In the extremities of the gland, the milk consists of only a little fluid, and cells completely filled with fat-globules; these cells sometimes fill the acini to the exclusion of all others, but sometimes are accompanied by paler epithelial cells, likewise containing more or less fat. These two kinds of cells have a common origin, either by a process of free cell-formation, or by the continual multiplication of the epithelial cells, in a manner analogous to the formation of the sebaceous matter of the skin (*vide* § 74). These cells, which I will call *milk-cells*, break down into their elements, the milk-globules, even before they leave the lacteal ducts; their envelopes, and generally, also, their nuclei, disappearing entirely, so that the excreted milk presents, as a rule, no trace of its mode of origin. At the most, there are found in it heaps of milk-globules, of various sizes and much isolated, which may also be called colostrum corpuscles, from their resemblance to those occurring in the colostrum.—The secretion of the milk, therefore, is essentially dependent upon a formation of fluid and fatty cells in the gland-vesicles, and, accordingly, belongs to the category of secretions in which morphological elements play a part. The affinities of this fluid are especially with those secretions which contain fat, as the sebaceous matter of skin, in which cells are found exactly similar to those in the acini of the mammæ and in the colostrum.

In newly-born infants, the mammæ very frequently contain a *small quantity of a fluid* resembling milk in its appearance and microscopical characters, the presence of which appears to be connected with the formation of the gland-canals.

Donné, the discoverer of the colostrum bodies, states, that in inflammations and swellings of the mammæ during lactation, the milk assumes the nature of colostrum; but this is contradicted by *d'Outrepont* and *Münz* (*Neue Zeitschr. für Geburtskunde*, bd. 10). During menstruation, *Donné* and *d'Outrepont* find colostrum corpuscles in the milk; and *Lehmann* (*Phys. Chemie*, ii. 327) states that they occur in the course of any acute affection which may supervene during lactation. They are regarded by *Donné* as a proof of bad milk. In the foot-rut of animals, *Herberger* and *Donné* have found the milk to possess more the character of colostrum. In milk which has become sour, the caseine is found coagulated in the form of granules, and the milk-globules gradually coalesce into larger drops. Blue and yellow milk contains, according to *Fuchs* (see *Scherer*, art. 'Milch,' in *Hand. d. Phys.*, ii. p. 470), infusoria, themselves without colour, which he calls *vibrio cyanogenus* and *xanthogenus*. These, when mingled with healthy milk, will impart a colour to it also; an observation which has been confirmed by *Lehmann* for blue milk: still, according to *Bailleul* (*Compt. rend.*, xvii., p. 1138) and *Lehmann*, a fungus also exists in such milk. *C. Nägeli* has also observed *red* milk, and found a vegetable formation of the nature of a protococcus in it.

For the *investigation* of the structure of the mammæ, those of pregnant or lactating females, or of women who have had children, should be selected, because it is only in these that the gland-vesicles are well developed. The glandular elements readily come into view by teasing out the smallest lobules; but, if it be desired to see their arrangement, fine sections of glands boiled in acetic acid and dried, are especially to be recommended; injected preparations may also be used for this purpose, and are not difficult to be obtained, when injected through the lacteal sacs. For the study of the *development of the gland*, fresh preparations, as well as others made by means of acetic acid, are absolutely necessary. The smooth muscular fibres of the *areola* are found by mere dissection, although not always easily, as they are often very delicate at other times than during pregnancy.

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OF THE VASCULAR SYSTEM.

§ 211. The vascular system consists of the *Heart*, the *Blood-vessels*, and the *Lymphatic Vessels*; and in the cavities of these structures are contained the blood and the lymph (including the chyle), with their innumerable morphological particles. The *lymphatic glands*, on the lymphatic system of vessels, are also to be enumerated as special organs.

I.—OF THE HEART.

§ 212. The *heart* is a thick muscular tube divided into four compartments, surrounded externally by a *serous membrane*, the pericardium, and lined internally by the endocardium, a continuation of the walls of the large vessels, especially of their tunica intima.

The pericardium resembles in its structure other serous membranes, especially the peritoneum. The parietal layer is considerably thicker than that which invests the heart; at its outer surface it is more fibrous, but towards its inner aspect, as far as the epithelium, it is provided with numerous networks of fine elastic fibres. The epithelium is of the pavement variety, and consists of one or two layers of elastic fibres. The visceral layer of the pericardium is partly connected intimately with the muscular fibres; but in other parts, the grooves particularly, is separated from them by ordinary adipose tissue; which latter not unfrequently appears as a subserous layer, covering almost the whole heart. This layer is also abundantly supplied with elastic fibrils. The *vessels* of the pericardium present the same arrangements as in other parts; and with regard to the *nerves*, branches of the phrenic and right recurrent of the vagus have been demonstrated in the parietal lamella (*Luschka*). Papilliform processes, like those on the pleura (see § 176), have been observed by *Luschka* upon the borders of the auricles.

The *muscular fibres* of the heart are red and transversely striated, yet differ in many respects from those of the voluntary muscles. The individual fibres are, on an average, one-third thinner (measuring 0·004‴ to 0·01‴), frequently more distinctly striated in the longitudinal than in the transverse direction, and break up with tolerable facility into fibrils and small particles (the sarcous elements of *Bowman*). Their sarcolemma is very delicate, or even *may not be demonstrable* at all except by the aid of re-agents. In these fibres, small fat granules are almost uniformly found, which are frequently disposed in series, along with the nuclei, in the axis of the fibre; and which appear very much enlarged and coloured when the fibres undergo degeneration. A still more important characteristic of the muscular fibres of the heart, is found, however, in the intimate union of their elements, which lie closely upon each other, with very little connective tissue between them; and they are also (as *Leeuwenhoek* pointed out, and as I have myself confirmed), united directly with each other. Except at the inner surface of the heart, the fibres nowhere form distinct bundles. The anastomoses of the muscular fibres, which are a general attribute of the fibres of the heart, are effected in man and mammalia by short bundles, oblique or transverse; they are for the most part narrow, but are extremely numerous, so that at many places of the ventricles and auricles (whether everywhere I know not), they are met with in every small piece. Moreover, there occur true divisions of the fibres, by means of which the thickness of a separate portion of a fibre may become more considerable than it was at its origin.

Fig. 193.

Anastomosing primitive bundles from the human heart.

The course of the muscular fibres in the heart is extremely complicated, and can only be described here in a general manner. The muscular fibres of the ventricles and auricles are completely separate from each other; but the chief place of origin for both alike is from the *ostia venôsa* and *arteriosa* of the ventricles. At the former place are situated dense, tendinous bands—the so-called *annuli*—the thinner one being in the right, the thicker in the left ventricle; these are generally described as rings situated at the insertion of the venous valves, but are more accurately designated as proceeding from the opening of the aorta both anteriorly and posteriorly; the densest portions of these bands is at the anterior circumference of the *ostia venosa*, and at the part which forms the partition; and from this circumstance they are also frequently described as being composed of two bands, curved forwards, with a posterior one situated in the auriculo-ventricular septum, and splitting these into two crura. The fibrous rings of the *ostia arteriosa* are considerably thinner than those of the *ostia venosa*, and are situated at the origin of the semilunar valves in the form of arcuately curved bands. On the auricles there are found: 1. fibres common to both auricles, in the form of transverse flat bundles, which pass from one auricle to the other, continuing their transverse direction, and are found especially on the anterior aspect, but also superiorly and inferiorly. 2. Special fibres confined to one auricle: some of these form true rings at the openings of the great veins, and at the apices of the auricles; but the mass of them form a pretty thick longitudinal layer beneath the endocardium, arising from the ostia atrio-ventricularia, and being particularly well marked in the right auricle, where it forms the so-named *musculi pectinati*. Besides these fibres, there also exist in the auricles, among those last mentioned, numerous small bundles, which, from their irregular relation, cannot be more minutely described. The dissepiment is, in part, common to both auricles. Its muscular fibres arise from the *posterior fibrocartilage*, situated at the front of the upper border of the ventricular septum, immediately behind the aorta; thence they proceed, on the right side, upwards and backwards, in an arcuate manner around the fossa ovalis (in which only thin fibres occur), and terminate partly upon the inferior cava, partly by forming a complete ring round the fossa: on the left side, they encircle the fossa ovalis in the opposite direction.

The muscular fibres of the ventricles are so arranged, that those of the outer and those of the inner surface everywhere proceed in a decussating direction; while between the two sets they present more or less distinctly, all transitions of the one direction into the other. The muscular fibres arise at the ostia venosa, and at the mouths of the aorta and pulmonary artery, partly directly, partly by means of short tendons; they run more or less obliquely, but some of them longitudinally or transversely; they bend round again after they have encircled a section of the ventricle in the longitudinal or transverse direction, and then terminate partly in the musculi papillares and chordæ tendineæ, partly by becoming attached again at the point from which they started. Thus, without being interrupted by tendons, they describe large loops or figures of eight running in very various directions, and almost everywhere more or less twisted around themselves.

The *endocardium* is a whitish membrane which invests all the depressions and irregularities of the inner cardiac surface, as well as the papillary muscles, their tendons, and the valves. It is best developed in the left auricle, where it is a quarter of a line thick, and is thinnest in the ventricles, so that in them the muscular substance appears through it of its natural colour. With regard to its *structure*, it almost everywhere consists of three layers, an epithelium, an elastic layer upon which the various thicknesses of the endocardium at different places depends, and a thin layer of connective tissue. The epithelial layer is usually simple, but according to *Luschka*, is sometimes a double stratum: its cells are flattened and polygonal, generally somewhat elongated, clear, and nucleated, measuring 0·007‴ to 0·012‴ in length. They are seated immediately upon the most superficial lamina of the elastic coat, which may be said to be composed entirely of very fine longitudinal fibres. The remainder of this middle coat is formed by an ordinary matrix of connective tissue, with interspersed nuclei, and is traversed by numerous networks of finer and coarser elastic fibres; indeed, in the auricles, these fibres are present in such numbers, even intermingled with true fenestrated membranes (see § 25), that the endocardium is here quite converted into a yellow elastic membrane of several layers. Lastly, there follows an outermost layer of connective tissue, which, although thin, may yet readily be pulled off as a whole in the ventricles, as well as in the auricles. It still contains fine elastic elements in the parts adjoining the elastic layer, and forms a loose layer, analogous to a subserous connective tissue, uniting the muscular substance to the proper endocardium. Upon the chordæ tendineæ, the endocardium only consists of the epithelium, and of the innermost elastic layer, whilst the loose layer of connective tissue is entirely absent: it is very thin also upon the trabeculæ of the right ventricle, and upon the musculi pectinati.

The *auriculo-ventricular valves* are laminæ proceeding from the fibrous rings of the ostia venosa; and we may distinguish in them, when they are tolerably thick, a middle layer (thicker on the left side) of connective tissue, with numerous networks of elastic fibres, in whose formation the radiations of the chordæ tendineæ are very essentially concerned; and on either side of this layer is a lamella of the endocardium in connexion with it. Towards the free borders, these three layers nearly coalesce into a single one composed of connective tissue, with fine networks of elastic fibres, over which the epithelium is still continued.—The semilunar valves present the same arrangement as those just described, except that they are thinner. In both sorts of valves, the endocardium is thicker on the side which is most stretched during life. A few muscular fibres of the auricles arise here and there from the outermost edge of the middle of the auriculo-ventricular valves; beyond these, the valves are free from muscular elements.

The blood-vessels of the muscular substance of the heart are very numerous, but differ in nothing from those of the transversely striated muscles (§ 83), except that, on account of the thinness of the fibres, the capillaries often surround several of them together. The endocardium is tolerably rich in vessels in its outer layer, but they extend sparingly only into the endocardium proper. In the auriculo-ventricular valves of animals, as also of man (*vide Luschka*, l. c. p. 182 and fig. 5), some small vessels are readily seen, which partly reach them from the papillary muscles, but chiefly from the base; some few of these are distributed scantily in the proper endocardial covering of the valve. According to the recent observations of *Luschka*, even the semilunar valves are provided with vessels.—But few lymphatics occur upon the parietal layer of the pericardium; on the other hand, they are present in large numbers upon the muscular substance beneath the visceral lamella, and can be easily demonstrated, as *Cruikshank* pointed out, when the heart is allowed to lie in water for some days. Their trunks collect in the grooves, run with the blood-vessels, and terminate in the glands behind and beneath the arch of the aorta at the division of the trachea, where they meet the lymphatics coming from the lungs. It is not yet determined whether the cardiac substance and the endocardium possess lymphatics, as is stated by some authors.—The nerves of the heart are numerous, and come from the cardiac plexus (beneath and behind the arch of the aorta), which is chiefly formed by the vagus and sympathetic. They proceed with the vessels to the right and left auricles and ventricles as the two coronary plexuses, of which the left is much larger than the right: hence they run towards the apex of the heart, partly accompanying the vessels, partly crossing the direction of them; then, after forming numerous anastomoses, mostly at acute angles, they dip into the muscular substance, some of them entering by the coronary furrow, and thus they arrive at their places of distribution, viz., the muscular tissue and the connective tissue of the endocardium. The cardiac nerves of man are mostly grey, and, with the exception of the largest, contain only fine and very pale nerve-tubes; but these are in great numbers, and are intermingled with a small number of nucleated fibres. Although the nerves, even in the endocardium, are dark-bordered and pretty abundant, yet it has not been possible hitherto to discover their terminations in this place any more than in the muscular substance. In the pike, however, *Martin* has observed them to end by dichotomous division with free terminations, in *the muscular* substance of the heart (Gött. Nachr. 1853, No. 6). Ganglia occur not only in the cardiac plexus at different places, but also, as *Remak* discovered in the calf, in the muscular substance of the auricles and ventricles, and the same holds good for man and other animals. These ganglia are best known in the frog, where they are seated especially in the septum and at the junction of the auricles with the ventricles, and they contain apolar and unipolar cells (*Ludwig*, *Bidder*, *R. Wagner*, and myself). The small fusiform swellings upon the outer nervous branches, especially described by *Lee*, are not ganglia, but only thickenings of the neurilemma.

Fig. 194.

Diagram of the left ventricle, with the septum, for the purpose of indicating the course of the muscular fibres. *a*, *a'*, *a''*. superficial fibres: *a*. on the anterior wall; *a'*. their course inwards at the apex of the heart; *a''*. passage of the same into the posterior papillary muscles; *b*. *b'*, *b''*. septal fibres of the right side; *b*. in their course downwards and forwards; *b'*. their passage into the apex of the heart, and internal muscular layer of the left ventricle, as also their termination in the anterior papillary muscle, *b''*; *c*—*c''''*. middle muscular layer; *c*. commencement from the right side of the ostium, and course on the anterior wall obliquely downwards to the left and posteriorly; *c'*. curve at the septum and course therein; *c''*, *c'''*. curve at the anterior wall, and course in the deeper portion of it, up to their termination in the ostium venosum, *c''''*.

II.—Of the Blood-Vessels.

§ 213. The blood-vessels are divided, with reference to their structure, into *arteries*, *capillaries* and *veins*; yet these three divisions are by no means broadly separated from each other, inasmuch as the capillaries are continued into the veins just as imperceptibly as they arise from the arteries. On the other hand, the two kinds of larger vessels, although constructed upon a generally similar plan, are sharply and definitely distinguished in many points.

With reference to the tissue composing the vessels, and its arrangement, the following general remarks may be made. While the true capillaries possess only a single coat, without any structure whatever, the larger vessels present, with few exceptions, three principal layers, which may be most fittingly designated as the inner coat, or *tunica intima*; the middle coat or circular fibrous coat, *tunica media*; and an outer coat, *tunica externa s. adventitia*. The *membrana intima* is the thinnest coat, and invariably consists of a cellular layer, the epithelium; generally also of an elastic coat, with the fibres disposed principally in the longitudinal direction; and to this again other layers of various kinds may be superadded, which likewise almost invariably retain the longitudinal direction. The *tunica media* is mostly a thick layer, and is the principal seat of the transverse elements, and of the muscular fibres of the vessels; in the veins, however, it contains numerous longitudinal fibres, and possesses in all the larger vessels more or less elastic elements and connective tissue. The *tunica adventitia*, lastly, has its fibres again arranged for the most part longitudinally; it is as thick, or even thicker than the middle coat; and consists of little else than connective tissue and elastic networks.

Fig. 195.

Elastic membrane from the tunica media of the human popliteal artery, with an indication of fibrous networks. Mag. 350 times.

On a closer examination of the several tissues composing the walls of the vessels, there are several points worthy of note. The connective tissue is almost everywhere fully developed, consisting of fine and coarse bundles and distinct fibres. Only on the smallest arteries and veins, it becomes a nucleated indistinctly fibrous tissue, passing at last into a delicate homogeneous membrane, in which nuclei may still be seen here and there. The elastic tissue appears nowhere in the body in such multifarious forms as in the vessels. We meet with wide-meshed loose networks of fibres, from the finest to the coarsest (fig. 17, p. 50), and again with the narrowest closest web of fibres which form almost a continuous membrane; and between these two forms we meet with all grades of transition; and we also observe every degree of transformation between the elastic web just described and the true elastic membranes, whose origin is often indicated by an elastic network of fibres, more or less indistinct, traversing them and exhibiting here and there an aperture. In other cases, the elastic membranes are perfectly homogeneous plates, either in the whole or in part of their extent, and are perforated by an uncertain number of holes (fig. 19, p. 51).—Transversely striated muscular fibre is found only at the openings of the largest veins into the heart, while the unstriped muscular elements are very widely distributed, especially in the middle-sized vessels, but also in the larger ones. Their contractile fibre-cells exhibit no peculiarity in the majority of vessels, except that their length hardly ever exceeds 0·04‴ to 0·06‴, and that they are united together, either directly or by connective tissue and elastic fibrils, into flat bundles and membranes of muscle, more rarely into networks. *In the larger* arteries, and in the smallest arteries and veins, shorter cells of various shapes are seen, which are, probably, a less developed condition of the muscular elements.

Certain peculiar lamellæ found in the tunica intima of the larger vessels, and consisting of fibres with elongated nuclei, and very delicate fibrous membranes, almost homogeneous, are regarded by *Henle* and later observers as being a metamorphosed epithelium. I prefer to consider these *striped lamellæ* of the inner coat as derived from the same formative-cells as the epithelium, which have developed themselves in a peculiar way.

The epithelium of the vessels (fig. 6, p. 35) appears in two forms. In the great veins especially, it is of the pavement variety, with polygonal cells, tending to be elongated. In most of the arteries, the epithelium is of the fusiform kind, with small pointed cells, 0·01‴ to 0·02‴ in length. An epithelium is present in the normal state of every vessel; but almost without exception it may be broken up into its elements without much difficulty; and like other simple epithelia, it experiences no constant detachment and re-formation. In the larger vessels, the epithelium is often continuous with the striped lamella before mentioned, without any line of demarcation between them; in the heart, and in the smaller vessels, it is sharply defined from the subjacent tissues.

Fig. 196.

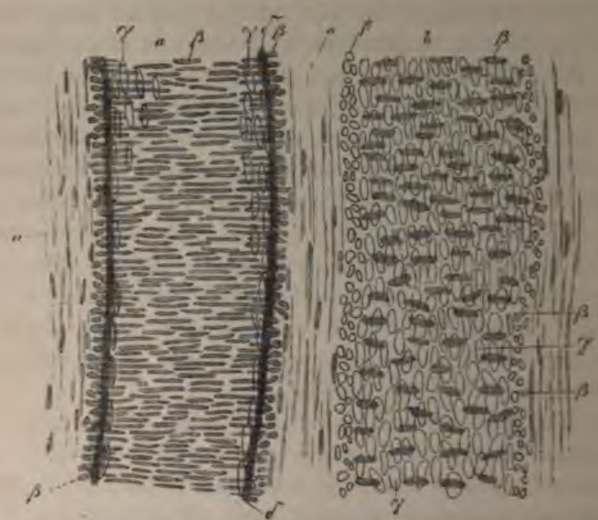
Muscular fibre-cells from human arteries, magnified 350 times. 1. from the popliteal artery; *a.* without, *b.* with, acetic acid; 2. from a branch, half a line in diameter, of the anterior tibial; *a.* nucleus of the cells.

All the larger vessels, down to those of ½‴ in diameter and under, possess nutrient vessels, the *vasa vasorum s. nutrientia*, which arise from small neighbouring arteries, and are chiefly distributed in the tunica adventitia, producing here a rich capillary network with roundish meshes, from which small veins arise and accompany their arteries, or, in the case of the vasa vasorum of the veins, pour their blood directly into the veins, from whose walls they proceed. According to the concurrent testimony of many authors, the tunica media of the larger arteries and veins also contains vessels, although in very small numbers, and only in its outer laminæ; whilst, on the other hand, the inner layer of the middle coat, and the whole of the tunica intima, always appear to me to be non-vascular, although even here some observers believe they have seen vessels. The inferior vena cava of the ox is shown to be provided with numerous vessels, as far as to its tunica intima. —Nerves, passing from the sympathetic and the spinal nerves, can be demonstrated with facility on many arteries, yet frequently appear only to accompany them. Where they penetrate into the tissue of the vessels they run only within the outer tunic, and in favourable cases, divisions and free terminations of their fine tubes can be perceived in animals (see my *Micros. Anat.* ii., 1, pp. 532, 533). Many arteries are completely destitute of nerves, as the majority of those in the substance of the brain and spinal cord, those of the choroid, of the placenta, as well as many arteries of muscles, glands and membranes, and hence it is evident that the walls of the arteries are not in such essential need of nerves, as is usually supposed. This is still more evident in the case of veins, for only on some of the larger ones have any nerves been demonstrated: they have been observed on the sinuses of the dura mater, on the veins of the vertebral canal, on the venæ cavæ, on the common jugular, iliac, and crural veins, and on the hepatic veins. Here also they arise from the sympathetic and the spinal nerves; but they have not yet been investigated with reference to their terminations. According to *Luschka*, they extend as far as to the innermost coat; but I have not yet succeeded in observing this.

§ 214. For the sake of easier description, the *arteries* may be divided into *small, middle-sized,* and *large,* according as their middle coat is *purely muscular,* composed of *muscular fibres* and *elastic fibres* intermixed, or of *elastic fibres* principally. This division is the more natural, as, along with the alterations in the structure of the middle coat, variations in several respects also occur in the outer and inner coat. It is a distinguishing mark of the arteries, that their middle coat possesses an unusual thickness, and consists of numerous, regularly disposed laminæ, whose elements run in a transverse direction. In the largest arteries, the tunica media is yellow, very elastic, and of great thickness; as the arteries become smaller, it progressively decreases in thickness and becomes more reddish and contractile, till, at last, immediately before the capillaries, it appears very thin, and then disappears. The whitish tunica intima is always much thinner than the middle coat, and varies within narrower limits, although it also bears a proportion to the size of the vessels; whilst, on the other hand, the tunica adventitia is actually considerably thinner *in the largest arteries than* in those of middling calibre, where its thickness is often equal to that of the middle coat, or may even be greater. In the more detailed account of the vessels, it will be best to commence with the smallest arteries, as being simplest in structure, upon which the others will readily follow.

Arteries below four-fifths of a line or a line in diameter, present, with few exceptions, the following structure, till near to the capillaries (fig. 197). The tunica intima consists of two layers only, an epithelium and a peculiar shining, less transparent membrane, which I will call *elastic inner coat*. The former has well-marked fusiform

Fig. 197.



An artery from the mesentery of a child, 0·062‴, and vein, δ, 0·067‴ in diameter, treated with acetic acid, and magnified 350 times. α. tunica adventitia, with elongated nuclei; β. nuclei of the contractile fibre-cells of the tunica media, seen partly from the surface, partly apparently in transverse section; γ. nuclei of the epithelial cells; δ. elastic longitudinal fibrous coat.

pale cells, with oval nuclei disposed longitudinally: groups of these can be extremely easily isolated, in entire shreds, or even as complete tubes, but the cells may also be demonstrated separately, and they then possess no slight resemblance to the fusiform cells of pathologists (also to the formative cells of elastic fibres and connective tissue); and, on the other hand, they much resemble the contractile fibre-cells: from the former of these, however, they are distinguished by their less pointed ends, and by their paleness, and from the latter by their stiffness, by the non-cylindrical nuclei, and by their chemical reactions. The elastic inner coat is, on an average, 0·001‴ thick, and is smoothly stretched out during life under the epithelium; but when the artery is empty, it almost always exhibits more or less large longitudinal plication, and frequently also numerous fine transverse folds, which (although it is perfectly homogeneous) give to this membrane a peculiar longitudinal striated appearance. Moreover, it almost always appears as a so-called *fenestrated* membrane, with well marked reticulated fibres of various sizes, and openings mostly small and elongated; more rarely, it has the structure of a true but very dense network of longitudinal elastic fibres, with narrow elongated fissures, and then completely agrees with the elastic lamellæ of the middle coat of the larger arteries, in its appearance, in its great elasticity, and in its chemical reactions.—The middle coat of small arteries, such as we are now considering, is purely muscular, without the slightest intermixture of connective tissue or elastic elements, and varies in thickness according to the size of the arteries (down to 0·03‴). Its fibre-cells, united to form lamellæ, can be pretty easily isolated by dissection in vessels not larger than one-tenth of a line, and in still smaller vessels they may be found by boiling and maceration in nitric acid of 20 per cent., and they are then seen to be beautiful fibre-cells, 0·02‴ to 0·03‴ long, and 0·002‴ to 0·0025‴ broad.—The tunica adventitia consists of connective tissue and fine elastic fibres, and is generally as thick, or even thicker than the tunica media.

The structure just described holds good for arteries as small as $\frac{1}{8}$‴ in diameter, but further on towards the capillaries it changes more and more (fig. 198). Even on arteries $\frac{1}{10}$‴, the adventitia no longer contains elastic fibrils, but only connective tissue with elongated nuclei, which, at first, is fibrous, but gradually becomes more and more homogeneous, retaining its nuclei, and, at last, is reduced to a thin, perfectly homogeneous envelope, which entirely disappears on vessels below 0·007‴.—The circular fibrous coat, on arteries below $\frac{1}{10}$‴ down to those of $\frac{1}{25}$‴, still possesses two or three layers of muscular fibres, and a thickness of 0·008‴ to 0·005‴; on smaller arteries, it forms only one layer, whose elements, at the same time, become shorter and *shorter, and, at last,* on vessels between

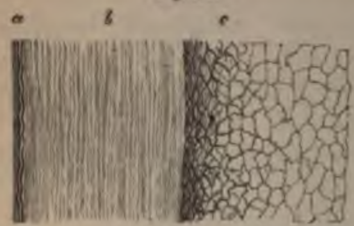
Fig. 198.

a. An artery 0·01‴, and *b.* a vein 0·015‴, from the mesentery of a child, magnified 350 times, and treated with acetic acid. The letters as in the previous figure; *e.* the tunica media of the vein, consisting of nucleated connective tissue.

0·03''' to 0·007''', they lapse into short, elongated, or oblong cells, 0·015''' to 0·006''', whose nuclei have no longer their elongated form. These more embryonic forms of contractile fibre-cells form a connected layer, as far as to vessels of 0·012''', but then gradually separate from one another (fig. 198), and completely disappear.—The tunica intima possesses an elastic coat on vessels as small as 0·028''' to 0·03''' in diameter; it is, of course, very delicate on its first appearance, and appears in a fully developed state only on arteries of 0·06''' to 0·08'''. The epithelium, however, can be traced on minute arteries of 0·07''', or even 0·01''' in diameter; but, it is to be observed, that its cells become at last incapable of isolation, so that their separate existence is only to be inferred from the presence of longitudinally oval nuclei placed closely together.

Arteries of medium size, above four-fifths of a line, or a line, up to those of two or three lines in diameter, present at first but little change in the outer and inner coats, but a considerable difference is found in the tunica media, which not only becomes thicker with the increase in size of the vessels (reaching 0·03''' to 0·12'''), but is also altered in structure. Its muscular layers become increasingly numerous, though their elements remain identical with those described in the smaller vessels; but along with the muscular fibres fine elastic fibres appear in the tunica media, and these unite to form wide-meshed networks, which, at first, run separately and without order among the muscular elements; but in the larger of the arteries at present under review, these elastic elements are accompanied by some connective tissue, and occasionally exhibit an inclination to form special laminæ, alternating with the muscular layers, without, however, losing the character of a continuous network pervading the whole middle coat. Thus the tunica media already loses its exclusively contractile structure, though it is to be admitted that the muscular fibres still retain a considerable preponderance.—The tunica intima of the medium-sized arteries has not unfrequently several layers between the elastic inner coat and the epithelium, among which the above-described striped lamellæ are the most conspicuous. These lamellæ,

Fig. 199.

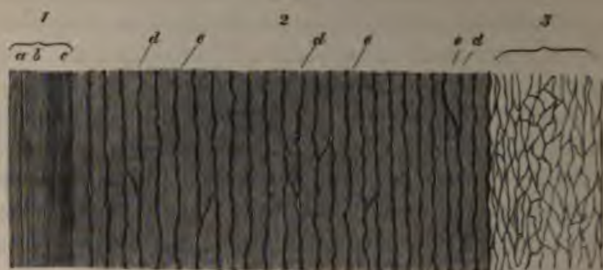


Transverse section of the human *art. profunda femoris*; magnified 30 times. *a*. Tunica intima, with the elastic layer (the epithelium is not visible); *b*. tunica media, without elastic lamellæ, but with fine elastic fibres; *c*. tunica adventitia, with elastic networks and connective tissue.

taken along with the fine elastic networks situated further outwards in a homogeneous, granular, or fibrillated connective substance, form a middle layer in the tunica intima of 0·006‴ to 0·05‴ in thickness, all of whose elements run together in the longitudinal direction, and are thus easily distinguished from the muscular layer of the tunica media, which, in some respects, has a resemblance to them.—Lastly, the tunica adventitia of these middle-sized arteries measures almost always more than the middle coat, and increases from 0·05‴ to 0·16‴ in thickness. Its elastic fibres become, at the same time, thicker and thicker; even in vessels of one line in diameter a thick collection of them can be recognised, just at the line where the external coat forms its well-defined boundary from the middle tunic. This elastic coat of the tunica adventitia becomes very beautiful in the largest vessels of this class, such as the external and internal carotids, the crural and brachial arteries, the profunda femoris, the mesenteric and cæliac arteries. In these, it measures 0·013‴ to 0·04‴ and upwards, and is partly made up of very distinct lamellæ, whose structure is often closely allied to that of the true elastic membranes. Moreover, the outer layers of the tunica adventitia also contain elastic networks; but these elements are here somewhat finer and form no lamellæ, but are more irregularly connected with each other.—The larger of the medium-sized arteries already present an approximation to the largest arteries in the structure of their tunica media; the elastic network of this coat occasionally forms actual lamellæ of some thickness, and, more rarely, even two elastic membranes; but these are still connected with each other throughout the whole thickness of the middle coat, and thus they are best distinguished from the elastic plates, which will be presently described as existing among the circular fibres of the middle coat of the larger arteries. The first indication of these lamellæ appears in the inner portion of the tunica media of the crural, superior mesenteric, cæliac, external iliac and brachial arteries, and in the external and internal carotids; whilst at the commencement of the tibialis antica and postica, and in the popliteal, they occur throughout the whole middle coat; they are, indeed, very beautifully developed in the latter artery, which has also usually somewhat thicker walls than the crural.

In the manner here described, then, and by intervening forms of tissue occurring in the other coats, the transition from the medium-sized to the largest arteries is very gradually effected. We will now examine the structure of the main arterial trunks of the body. As for the tunica intima, the epithelial cells are not usually so elongated here as in the smaller arteries, though they are still fusiform and 0·006‴ to 0·01‴ in size. The remaining part of this coat does not necessarily become thicker with the size of the vessels; it exhibits, however, especially in the aorta, a great

Fig. 200.



Transverse section of the aorta below the superior mesenteric artery. 1. Tunica intima; 2. tunica media; 3. tnnica adventitia. *a*. Epithelium; *b*. striped lamellæ; *c*. elastic coat of the tunica intima; *d*. elastic lamellæ of the tunica media; *e*. muscular fibres and connective tissne of the same; *f*. elastic networks of the tunica adventitia. From the hnman subject. Magnified 30 times, and treated with acetic acid.

disposition to become thickened, so that it is often difficult to determine its normal thickness. With reference to its structure, it chiefly consists of lamellæ of a clear substance, which are sometimes homogeneous, sometimes striated, or even distinctly fibrillated. This has, for the most part, the characters of connective tissue (*Eulenburg* obtained a small quantity of gelatine from the tunica intima), and is traversed by finer and coarser longitudinal elastic networks. As a rule, these networks become denser and denser, and their elements increase in thickness from within outwards; and at the boundary of the tunica intima and the tunica media, the inner coat presents either a dense, elastic, reticulated coat, or a true fenestrated membrane, more or less fibrous, which obviously corresponds to the elastic inner coat of the small arteries. Immediately beneath the epithelium, the elastic fibrous networks are either very fine, or are represented by one or several clear layers of the striped lamellæ, which, when they contain nuclei, often appear to consist of coalesced epithelial cells; but when homogeneous and without nuclei, approximate rather to pale elastic membranes.—In the circular fibrous coat of the larger arteries a new element appears, viz., special elastic membranes or plates, which, except in the transverse course of their fibres, are constructed in all essential respects like the elastic inner coat, particularly like that of the smaller arteries, sometimes forming very dense networks of elastic fibres, sometimes truly fenestrated membranes with indistinct fibrillation. These membranes, 0·001‴ to 0·0012‴ in thickness, may amount to fifty or sixty in number, and alternate regularly at distances of 0·003‴ to 0·008‴, with layers of smooth muscular fibres running transversely; among which is seen connective tissue, with networks of elastic fibres of medium size. These elastic membranes are not, however, to be regarded as tubes regularly encased in muscular fibres, which fill their interspaces, and thus isolate them from each other. They are rather to be considered as connected with each other, and with the fine elastic network, which, in variable amount, traverses the muscular fibres; and they are not unfrequently interrupted at different places, or represented by ordinary elastic networks. The elastic plates are seen to most advantage and most regularly arranged in the abdominal aorta, the innominate artery, the common carotid, and in the smaller arteries of the class we are now considering; their disposition, however, varies so much in different individuals, that without being in possession of very extended investigations, it is scarcely possible to state anything generally applicable.—The tunica media of the largest arteries is further distinguished by the slight development of its muscular fibres. Contractile fibre-cells are, indeed, to be found in the largest arteries throughout all the laminæ of the tunica media; but, compared with the other elements of this coat, viz., the elastic plates, the connective tissue, and the finer elastic networks, the muscular element constitutes only an unimportant part (not more than one-third or one-fourth); and again, the cells of the muscular tissue are so undeveloped, that it appears very doubtful whether they possess any power of contraction worthy of mention. In the aorta and the trunk of the pulmonary artery especially, the fibre-cells are often found in the inner layers of the tunica media not longer than 0·01‴, and 0·004‴ to 0·006‴ broad, quite flat (so that they are not unlike to certain epithelial cells), irregular in form, rectangular, and fusiform or club-shaped, but still they preserve the well-known cylindrical nuclei. In the outer laminæ of these vessels, the fibre-cells become narrower and longer, up to 0·02‴, and, *at the same time*, more similar to the fully-developed mus-

Fig. 201.

Muscular fibre-cells, from the innermost layers of the human axillary artery; magnified 350 times. *a*. Without, *b*. with acetic acid; *a*. nucleus of the fibres.

cular fibre-cells of other organs; yet even here they retain a somewhat stiff and peculiar appearance. In the carotid, axillary, iliac, and subclavian arteries, the contractile elements are more developed, and, accordingly, the middle coat of these vessels has not the pure yellow colour of that of the largest arteries, but more of a reddish tinge.—The tunica adventitia of the largest arteries is thinner, both relatively and absolutely, than that of the smaller, amounting to only 0·04‴ to 0·02‴. Its structure is, upon the whole, the same as in other arteries, yet its inner elastic layer is much less developed, and, on account of the thick elastic elements in the tunica media, it is but little marked-off from the latter coat.

The tunica intima, also, of certain arteries contains smooth muscular fibres, as I have found in the axillaries and popliteals of man, and as *Remak* has also lately demonstrated in the visceral arteries of mammalian animals. In the large arteries of man, this coat is very frequently thickened, and then a great increase of the striped lamellæ more especially takes place.—In the tunica media, muscular fibres are not entirely absent in any artery; but they are wanting on the arterial branches of the retina, which measure less than 0·02‴. —The tunica adventitia of large arteries contains muscular fibres in animals, but none in man. According to *J. Lister* (*Trans. of Royal Society of Edin.*, 1857, and *Quart. Journ. of Micr. Sc.*, Oct., 1857, p. 8), the smallest arteries of the frog's web show contractile fibre-cells, which measure from $\frac{1}{180}$ to $\frac{1}{250}$ of an inch, and run in a spiral direction, making one-and-a-half up to two-and-a-half turns round the inner coat of the vessel; and such fibre-cells in a single layer constitute the only muscular elements of the vessel.

§ 215. *Veins.*—The veins, also, may be divided into three groups, small, medium-sized, and large; but these groups cannot be so definitely separated from one another, as was the case in the arteries. The veins invariably possess thinner walls than the arteries, and this is dependent upon the smaller amount of their contractile elements, as well as upon the more scanty development of their elastic parts; and hence the veins are more flaccid and less contractile.—The tunica intima is frequently of the same thickness in large as in middle-sized veins; it is less developed than in the arteries, but, in all other essential points, is similarly constructed. The tunica media, which is never yellow, but mostly reddish-grey in colour, contains much more connective tissue, and fewer elastic and muscular fibres, and it always presents the very distinguishing feature of laminæ running longitudinally as well as transversely. This coat is usually thin, though, in the middle-sized veins, it is even absolutely thicker than in the large, and, in such veins, it is best provided with muscular fibres.—The tunica adventitia, lastly, is generally the thickest layer, and, indeed, its relative and absolute thickness increases with that of the vessels. It completely agrees in its composition with that of the arteries, except that in many veins, those of the abdominal cavity especially, we find in it very well-developed, longitudinal, muscular fibres, which give the whole wall of the vein a peculiar character.

The smallest veins (fig. 198, *b*) may be said to consist only of nucleated connective tissue, indistinctly fibrous or homogeneous, together with an epithelium. The component cells of the latter are oblong or round, with oval or even roundish nuclei; whilst the former tissue forms an outer coat, which is relatively thick, and a thinner layer (fig. 198, *e*), representing the tunica media, the fibres of both coats running in the longitudinal direction. Below 0·01‴, the veins gradually lose the outer connective tissue and the epithelium, and the middle coat passes, to all appearance, into the structureless coat of the capillaries. A muscular coat, and usually, also, a layer of circular fibres, appear first in veins above 0·02‴ in diameter; when first seen, these elements appear as transversely oval cells, at first widely apart from each other, with short oval, or even roundish transverse nuclei. These cells gradually become longer and more numerous, and at last, on vessels 0·06‴ to 0·08‴ in diameter, form a continuous layer (fig. 197), which, however, is never so well developed as that of the corresponding arteries. The structure of the veins remains the same as far as those of 0·1‴ in diameter; but their fine elastic networks gradually appear externally to the epithelium in the muscular coat and tunica adventitia, while the muscular layers themselves increase, and connective tissue and fine elastic fibres become developed between their elements.

Veins of medium size, from one to four lines in diameter, comprise the cutaneous and deep veins of the extremities, as far as the brachial and popliteal, and the visceral and cerebral veins, with the exception of their main trunks. Such veins are distinguished (more especially those of the lower extremities) by the greater development of their circular fibrous coat, which, as in the arteries, is reddish-yellow in colour, and arranged transversely. Still, even where it possesses the greatest thickness, this coat never equals that of the corresponding arterial vessels, and does not exceed 0·06‴ to 0·07‴ in thickness. It is distinguished also from the similar structure in the arteries by possessing not only transverse, but also longitudinal layers. The former are represented by ordinary, wavy connective tissue, with fine, loose, elastic fibres, readily separable from each other (the so-called nuclear fibres), and contains a large number of smooth muscular fibres, whose fusiform elements measure 0·02‴ to 0·04‴ in length, and 0·004‴ to 0·007‴ in breadth, and present the ordinary characters of the contractile fibre-cells; on the other hand, the longitudinal laminæ consist of true reticulated elastic fibres, some thicker than others, but all of the coarser variety. With regard to the mode of arrangement of these tissues with one another, there follows upon the tunica intima in certain veins (popliteal, profunda femoris, saphæna major and minor), a longitudinal layer, 0·01‴ to 0·04‴ thick, formed entirely of connective tissue with fine elastic networks; while in certain other veins, muscular elements extend even as far as the innermost layers. In this case, there is found immediately external to the inner coat a *transverse* layer of muscular fibres, mixed with connective tissue and elastic fibrils—these three tissues always accompanying each other in such veins; next there follow layers of longitudinal elastic network, alternating regularly with layers of transverse muscular fibres and connective tissue, so that the middle coat of these veins somewhat resembles that of the largest arteries. It is, however, to be remarked, that these elastic networks, although densely interwoven, are yet never converted into homogeneous membrane; they are, moreover, interrupted here and there, and, as longitudinal sections show, are invariably connected with one another throughout the tunica media. The number of these elastic lamellæ varies from five to ten, and their interspaces measure 0·004‴ to 0·01‴.—The tunica intima of the middle-sized veins measures 0·01‴ to 0·04‴ in thickness, and consists, in its thinner form, of only an epithelium, with shorter, though still elongated cells, of a striped, nucleated lamella, and of an elastic longitudinal layer, which corresponds to the elastic inner coat of the arteries, though it scarcely ever appears as a truly homogeneous, fenestrated membrane, but rather as an extremely dense, extended network of finer and coarser elastic fibrils. Where the tunica intima is thicker, the striped lamellæ multiply and appear in variable number on the inner aspect of the elastic longitudinal layer, before described as forming the outer limit of the tunica intima. I have also observed smooth muscular fibres in the inner coat of the veins of the gravid

Fig. 202.

Transverse section of the *vena saphena magna*, at the malleolus; magnified 50 times. *a*. Striped lamellæ and epithelium of the tunica intima; *b*. elastic coat of the same; *c*. longitudinal inner layer of connective tissue of the tunica media, with elastic fibres; *d*. transverse muscular fibres, and *e*. longitudinal elastic networks disposed in lamellæ; *f* tunica adventitia.

uterus, as well as in the saphena major and popliteal veins; and this observation has been confirmed by *Remak* in the visceral veins of certain mammalia.—The tunica adventitia of these veins is almost invariably thicker than the tunica media, frequently twice as thick, more rarely of the same strength. As a rule, it contains only elastic tissue and ordinary connective tissue, longitudinally arranged; the elastic elements are variously connected together, often forming very beautiful elastic reticulate coats, with thick fibres. Those visceral veins, however, which will be presently described as possessing longitudinal muscular fibres in the outer coat, also present similar elements for a certain distance on their branches.

The largest veins are distinguished from those of medium diameter by the slight development of the tunica media, and especially of its muscular fibres; but their loss in this situation is often compensated by the appearance of contractile elements in the adventitia.—The tunica intima measures, as a rule, 0·01‴ in thickness, and presents the same structure as in the veins of medium size. More rarely, as, occasionally, in the vena cava inferior, in the trunks of the hepatic, and in the innominate vein, it increases to 0·02‴ and even 0·03‴; this increase in thickness being due to the striped lamellæ with nuclei, and to fine, longitudinal, elastic networks, never to the development of any muscular layer.—The tunica media measures, on an average, 0·02‴ to 0·04‴, but may amount to 0·06‴ to 0·12‴ in exceptional cases, as in the commencement of the portal trunk, in the uppermost part of the abdominal portion of the inferior cava, and at the mouths of the hepatic veins. On the other hand, it may be entirely wanting, as in the greatest part of the vena cava on the liver, and in the further course of the largest hepatic veins. Its structure is essentially the same as in the former instances, only that the longitudinal elastic networks are variously connected with each other, and are less distinctly disposed in lamellæ, or are even not so disposed at all; moreover, the transverse muscular fibres are scanty and indistinct (even where the tunica media possesses the considerable thickness above-mentioned), and are intermingled with more numerous transverse bundles of connective tissue. I have observed the muscular fibres of the tunica media most developed in the splenic and portal veins; they appeared to me to be completely absent at certain spots of the abdominal vena cava below the liver, and they are wholly wanting, also, in the subclavian vein and in the terminal portions of the superior and inferior vena cava.

—The tunica adventitia of the largest veins is invariably thicker than the middle coat, being often twice to five times as thick, and exhibits the important peculiarity in its structure, pointed out by

Fig. 203.

Longitudinal section of the inferior vena cava, at the liver; magnified 30 times. *a.* Tunica intima; *b.* tunica media, without muscular fibres, only containing areolar tissue and elastic fibres; *c.* internal laminæ of the tunica adventitia; *α.* longitudinal muscular fibres of the same; *β.* circular areolar tissue of the same layer; *d.* external part of the tunica adventitia without muscular fibres.

Remak, that in certain of these veins, at least, the outer coat contains a large number of longitudinal muscular fibres. These are most conspicuous in the hepatic part of the inferior vena cava, where they were first pointed out by *Bernard* (*Gaz. Méd. de Paris*, 1849, xvii. 331). Here they are arranged in fasciculi, 0·01‴ to 0·04‴ in diameter, which form a network traversing the inner half or inner two-thirds of the outer coat, and attaining sometimes a thickness of 0·22‴; where the middle coat is absent, this muscular layer of course lies directly upon the tunica intima. Besides, in this situation, *Remak* and myself have also found these longitudinal contractile fasciculi very well developed in the trunks of the hepatic vein, in the trunks of the vena portæ, and in the upper part of the inferior vena cava; and I have tracked them as far as the splenic vein, the superior mesenteric, the external iliac and renal veins. In these situations, the longitudinal fasciculi never contain any connective tissue, but probably elastic fibres in a certain number. The vena azygos also exhibited a few muscular elements in its outer coat, but they were absent throughout in the upper veins. It was only in the renal veins and the vena portæ that these muscular fibres extended through the whole thickness of the tunica adventitia, for, in the other veins mentioned, a larger or smaller part of it externally remained free from muscle, and consisted, as usual, of longitudinal connective tissue and elastic fibrous networks. This circumstance gave to the muscular layer of the tunica adventitia the appearance of a special vascular coat, and might have produced a confusion between it and the tunica media, which in these vessels is, as before stated, undeveloped or even absent. The error, however, could be readily avoided by tracing the condition of the parts from the smaller veins onwards. The contractile elements of the tunica adventitia are 0·02‴ to 0·04‴ in length, and present the usual characters; besides this muscular layer and the numerous longitudinal elastic networks, the outer coat of the largest veins invariably contains a certain quantity of connective tissue, which appears always to run in a transverse direction; so that even in these large veins the transverse elements are not unrepresented, although they no longer exhibit muscular fibres as their chief components. All the large veins which open into the heart possess, for a short distance, an outer circular layer of the same kind of muscular fibres which occurs in the heart, characterised here also by anastomoses of the primitive bundles. According to *Räuschel*, they extend along the upper vena cava as far as the subclavian vein, and are also to be found upon the main branches of the pulmonary veins; in the former situation, according to *Schrant*, they are longitudinal, and are found even towards the interior of the coat of the vessel.

We have still to make special mention of certain veins, in which the muscular elements are excessively developed, and of others in which they are entirely absent. To the former class belong the veins of the pregnant uterus, in which, besides the tunica media, the inner and the outer coats also present longitudinal muscular layers, whose elements exhibit the same colossal development in the fifth and sixth months of pregnancy as those of the uterus itself. The veins which are wholly destitute of muscular fibres are: 1. The veins of the maternal portion of the placenta, in whose walls large cells and fibres occur external to the epithelium, which I regard as undeveloped connective tissue. 2. The majority of the veins of the cerebral substance and pia mater. These vessels are made up of a simple layer of roundish epithelium, a thin longitudinal layer of connective tissue with separate longitudinal nuclei, representing the tunica media, and lastly, a tunica adventitia, more homogeneous in the smaller vessels, but fibrillated and nucleated in the larger. It is only rarely that a slight indication of muscular fibres is exhibited, and then it is in the middle coat of the largest of these veins, as represented in fig. 197. 3. The sinuses of the dura mater and the veins of *Breschet* in the bones. These are lined by a pavement-epithelium, and possess, external to it, a layer of connective tissue, sometimes with fine elastic fibres, which passes continuously into the tissue of the dura mater and internal periosteum. 4. The venous spaces of the corpora cavernosa (see § 200), and of the spleen of certain mammalia (see § 169). 5. The veins of the retina.—The valves of the veins chiefly consist of distinct connective tissue, which runs parallel to their free border, and contains numerous elongated nuclei, as well as scattered elastic fibres, wavy and mostly free, some of them being of the thicker variety. On the surface, there is found either a simple epithelium with short cells, or, in addition, a very fine elastic network beneath the cells, disposed principally in the longitudinal direction. The valves, accordingly, may be regarded as continuations of the middle and inner coats, although, as far as I have seen, muscular fibres are wanting in them. *Wahlgren*, indeed, believes he has seen them in large valves, but *Remak* regards the appearance of them as caused by the outer wall of the vein in the neighbourhood of the valves, where the other two coats happen to be thin.

§ 216. *Capillaries, Vasa Capillaria.*—With the single exception of the cavernous structures in the sexual organs and in the uterine placenta, all the arteries and veins of the human body are connected by abundant networks of microscopically fine vessels, which, on account of their narrow calibre, have received the above designation. They everywhere consist of a single, structureless coat with cell-nuclei, and are thus distinguished very essentially from the larger vessels; still the transition to the arteries on the one side and to the veins on the other is quite imperceptible, so that at a certain point it is quite impossible to recognise the characters assigned by the histologist as the distinguishing marks of the one or the other division of vessels; such vessels, therefore, may be best designated, according to the side on which they lie, as venous or arterial *vessels of transition*, and without further alteration in the general arrangement, we may rank them with the capillaries.

The proper capillaries, when narrowly examined, present the following conditions. Their structureless coat is perfectly bright and clear, sometimes delicate and bounded by a simple contour, sometimes thicker, up to 0·0008‴ and 0·001‴, and with a distinct double contour. It completely agrees in its microscopical reactions with old cell-membranes and with the sarcolemma of the transversely striated muscular fibres (§ 85); and with regard to its other properties, it is perfectly smooth internally and externally, tolerably resistant and elastic, notwithstanding its fineness, yet, in all probability, it is not contractile. It always, and without exception, possesses a certain number of elongated cell-nuclei, of $0{\cdot}003'''$ to $0{\cdot}004'''$ in size, which are sometimes disposed at wider intervals, and then generally alternate on the two sides of the vessel, but are sometimes nearer, or even quite close together. In thin vessels, these nuclei have their seat upon the inner side; but in thicker ones they are placed in the substance of their wall, in such a manner that they not unfrequently occasion projections of the walls outwards. The diameter of the capillaries, in man, varies between $0{\cdot}002'''$ and $0{\cdot}006'''$, and they may, for the facility of description, be again divided into a finer sort, measuring from $0{\cdot}002'''$ to $0{\cdot}003'''$ in diameter, and having scanty nuclei and thin walls; and into a coarser kind, $0{\cdot}004'''$ to $0{\cdot}006'''$, with thicker coats and numerous nuclei; the two groups, it is to be understood, are not separated by any natural limit.

By the union of the capillaries arise the capillary networks, *retia capillaria*, which have been already treated of in detail in the description of the several organs and tissues, and will, therefore, only be shortly spoken of here in general terms. Their forms, in spite of considerable variations, are still pretty constant for the several organs, and, according to their uniformity or peculiarity, are more or less characteristic. The various forms depend, in great measure, upon the arrangement of the elementary parts, but also upon the energy of the functions. With regard to the former, there are, in many organs, certain ultimate tissues, into which vessels never penetrate, such as the transversely striated muscular fibres, the bundles of connective tissue, the nerve-tubes, cells of all kinds, and gland-vesicles; and the course of the capillaries is definitively determined ac-

Fig. 204.

Finest vessels of the arterial side. 1. Smallest artery; 2. transition vessel; 3. coarser capillaries; 4. finer capillaries. *a*. Structureless membrane, still with some nuclei, representative of the tunica adventitia; *b*. nuclei of the muscular fibre-cells; *c*. nuclei within the small artery, perhaps appertaining to an epithelium; *d*. nuclei of the capillaries of the transition vessels. From the human brain; magnified 300 times.

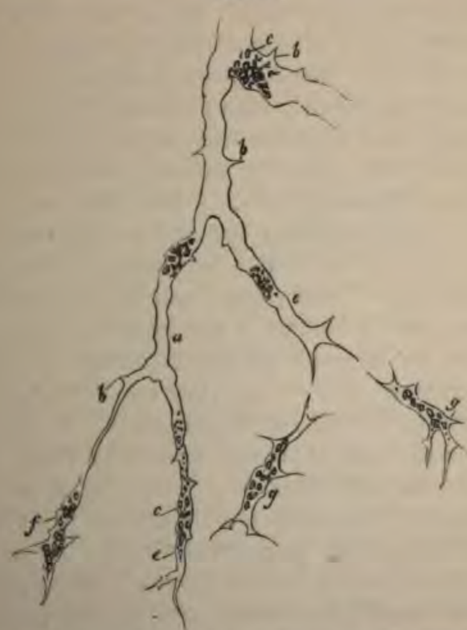
cording as they lie among one or other of these elementary tissues; thus they present sometimes more elongated meshes, sometimes roundish, narrower, or wider networks. The physiological energy of the parts is still more important, as determining the arrangement of the capillary plexuses; and it is a general law, that the greater the activity of an organ, whether expressed in contractions or sensations, secretion or absorption, the denser are the capillary networks, and the more abundant is the quantity of blood supplied to it. The capillary networks are closest in the organs of secretion and absorption, as in the glands, above all in the lungs, the liver, and the kidneys; next in the skin and mucous membranes; they are much wider in the organs which receive blood only for the sake of their own nourishment and for no other object, as in the muscles, nerves, organs of the senses, serous membranes, tendons, and bones; yet even here differences occur; the muscles and the grey nervous substance, for example, being much more abundantly supplied than the other parts mentioned. The diameter of the capillaries themselves present almost exactly a converse condition; for they are finest (0·002‴ to 0·003‴), and their walls are thinnest, in the nerves, muscles, in the retina, and in the Peyerian follicles; next, in the mucous layer of the skin, and in the mucous membranes, they amount to 0·003‴ to 0·005‴ in diameter; in the glands and bones, lastly, they reach a diameter of 0·004‴ to 0·006‴; and in the compact substance of the latter, although no longer possessing quite the structure of capillaries, they measure even 0·008‴ and 0·01‴. Physiology is not in a position to explain all these differences in detail, through the deficiency of our knowledge of the laws of diffusion through the different capillary membranes, and also because the finer modifications of the circulation in the several organs are completely unknown to us.

The manner in which the capillaries pass into the larger vessels is difficult to follow. Towards the arteries, the capillaries, as they become broader, receive more closely disposed nuclei, and then become covered externally with a structureless tunica adventitia and with separate muscular cells; and in this manner they already have the appearance of the narrowest arteries when they have reached a diameter of 0·007‴ (fig. 204, 1). Epithelial cells then appear to take the place of the nuclei, while the capillary membrane either disappears, or becomes continuous with the elastic inner coat. The venous vessels of transition do not become characteristic for a longer distance. The first structure that is here superadded to the capillary membrane is an outer, homogeneous, nucleated layer, which may be regarded as a kind of connective tissue; and while the nuclei of the capillary vessels move closer together, this layer gradually coalesces with the membranous tube. In vessels of 0·01‴, the internal nuclei are already so numerous, as to present unmistakeably the characters of the epithelium; and the outer layer has by this time become increased by a nuclear lamina, the tunica adventitia, so that the vessel is now distinctly lamellated (fig. 198), and we may properly give it the name of a vein. The capillaries, accordingly, appear to become transformed into the larger vessels by the superaddition of layers, both on their inner and outer sides; their own coat, meanwhile, coalescing with these, and being, perhaps, continued into the fibrous layer of the tunica intima.

III.—Of the Lymphatic Vessels.

§ 217. The lymphatics, with the exception of their contents, agree so nearly with the veins, that a short exposition of their structure will suffice.

Fig. 205.



Capillary lymphatic vessels, from the tail of a tadpole; magnified 350 times. *a.* Membrane of the same; *b.* processes which they form; *c.* remains of the contents of the cells which form these vessels, in which nuclei lie concealed; *e.* cæcal terminations of the vessels; *f.* such a one still pretty distinctly recognisable as a formative cell; *g.* isolated formative cell in the act of uniting with the real vessels.

The commencements of the lymphatics are only known with certainty in a single place, viz., in the tails of batrachian larvæ, where I discovered them in 1846 (*Annal. d. Sc. Natur.*, 1846), and here (fig. 205) they are seen to possess essentially the same structure as the blood-capillaries. These capillary lymphatics, which spread out in beautiful ramifications in the transparent edges of the tail, from an upper and lower *vas lymphaticum caudale*, exhibit in the trunks, as well as in the minuter vessels, a single, very delicate, structureless coat, with nuclei upon its interior; and they are distinguished in their structure from the blood-capillaries of the larvæ solely by the presence of numerous fine-toothed processes of various lengths proceeding from their membrane, so that they have a peculiar sinuous appearance. The commencement, also, of these vessels, 0·002‴ to 0·005‴ broad, is also peculiar, for they form but few anastomoses, but commence almost always by fine pointed extremities, even in the fully-developed tail (fig. 205).—In the first edition of my German manual, I indicated two other situations in which the commencement of lymphatics had been unequivocally observed; but these observations have again become doubtful by more recent investigations. The vessels which were figured by me as lymphatics in the trachea of man (*Mikr. Anat.*, fig. 279), were probably nothing else than blood-vessels peculiarly metamorphosed. *Virchow*, at least, has recently found vessels in the mucous membrane of the trachea and intestine transformed into whitish widened canals, filled with fatty granular masses, on which he observed, also, terminations apparently cæcal; and these vessels evidently belonged to the sanguiniferous system; an observation which, if it does not completely invalidate my former views, yet deprives them of all certainty. With regard, secondly, to the chyle-vessels of the intestinal villi, I believe I can positively answer for them here; but when an observer of the authority of *Brücke* totally denies their existence (see § 153), they can no longer be classed among the number of well-established facts. If the commencements of the chyle-vessels be not known in these places, it is certain that they are not known in any other case, or in any other place; and although the results of injections point to the commencement of lymphatics by networks (*Mikr. Anat.*, ii. 1, p. 22, 23), yet these have never yet been narrowly investigated with the aid of the higher magnifying powers, and, in some parenchymatous organs, no result whatever has yet been attained by means of injections.

The transition of the lymphatic capillaries into the larger lymphatics has been but little investigated. According to *Brücke*, an epithelial layer can be detected over the nuclei in those chyle-vessels of the intestinal walls which already possess valves, and which measure 0·02 of a millimetre; while no epithelium is found in the smaller valveless branches: these soon lose their walls, and communicate freely with the spaces of the tissue before described. It was not possible, on either the one or the other of these vessels, to distinguish a special wall apart from the connective tissue of the tunica adventitia surrounding them; indeed, layers of connective tissue appeared to form the whole wall of the vessel as far as the epithelium, though it should be mentioned, that in the valved vessels of the submucous tissue smooth muscular fibres were also found (*Sitzungsber. d. Wien. Akad. vom März*, 1853).

The finest lymphatic vessels which have come under my own observation have measured $\frac{1}{10}'''$, $\frac{1}{7}'''$ to $\frac{1}{6}'''$, and, except in the thickness of the individual layers, have completely agreed with larger vessels which measured $1'''$ to $1\frac{1}{2}'''$. These medium-sized lymphatics possess three coats. The tunica intima consists of an epithelium whose cells are elongated, though still rather short, and of a simple elastic reticulate coat, which is rarely double, and has its fibres disposed in the longitudinal direction; with reference to the thickness of its fibres, and the narrowness of its meshes, these are points subject to considerable variation, yet it never becomes a thick fibrous coat or true elastic membrane (according to *Weyrich*, this coat is absent in the lymphatics of the mesentery, while, on the other hand, I have always found it in those of the lumbar plexus and of the extremities). Next follows a thicker tunica media, composed of transverse smooth muscular fibres, with fine elastic fibres likewise disposed transversely; lastly, a tunica adventitia, made up of longitudinal connective tissue, with scanty networks of fine elastic fibre, and a larger or smaller number of smooth muscular fasciculi, running obliquely and longitudinally. I have found these latter in the lymphatics of the extremities, on vessels of $\frac{1}{10}'''$ in diameter, and regard them as a good mark of distinction between lymphatics and small veins (see my *Micr. Anat.*, ii. 1, p. 236).

Fig. 206.

Transverse section through the coats of the thoracic duct, of man; magnified 30 times. *a.* Epithelium, striated lamellæ, and inner elastic coat; *b.* longitudinal connective tissue of the middle coat; *c.* transverse muscles of the same; *d.* tunica adventitia, with *e.* the longitudinal muscular fibres.

The *thoracic duct* differs in some respects from the smaller lymphatics. The epithelium itself presents no peculiarity, but is followed by some striped lamellæ, and then by an elastic reticulate coat, with its fibres disposed longitudinally; still the whole tunica intima scarcely measures 0·006‴ to 0·01‴ in thickness. The tunica media, 0·025‴ thick, commences by a very thin layer of longitudinal connective tissue, with fine elastic fibres, while the remainder is made up of a transverse muscular laminæ, with fine elastic fibres. The tunica adventitia, lastly, contains longitudinal connective tissue, together with elastic fibres, and separate reticulated fasciculi of longitudinal muscular fibres.—The valves of this canal, and of the lymphatics in general, completely agree with those of the veins.—The blood-vessels which supply the coats of the lymphatics, present the same condition on the thoracic duct as on the veins.—No nerves have hitherto been found on them.

Brücke has recently attempted to prove, on physiological grounds, that the lymphatics at their origin cannot be provided with any walls (*Denkschr. d. Wien. Akad.* vi. pp. 22, *et seq.*). Setting aside the boldness of such a method of proof, in the imperfect state of this branch of physiology, *Brücke's* deductions are opposed to actual facts. There is no difficulty in convincing oneself that certain lymphatics in the tadpole do really begin by positively closed extremities.

§ 218. *Lymphatic Glands.*—The larger lymphatic glands, in their normal condition, consist, like the suprarenal capsules, of an *envelope*, of a *cortical*, and of a *medullary substance*. The envelope encloses the gland completely, with the exception of one or more places where the larger blood-vessels enter, and the efferent lymphatic vessels pass out; this may be designated the 'hilus' of the gland. The envelope is more delicate on the glands situated in the large cavities of the body, than on those of the external regions: in its structure it is wholly composed, in man at least, of connective tissue, in which are interspersed numerous fine elastic fibrils (nuclear fibres), and their formative elements, the plasmatic cells. In the lower animals, according to *O. Heyfelder*, especially in the mouse, contractile fibre-cells also occur in it; but *Beck* and *Remak* have not been able to find them (*Jahresb.*, v. HENLE, 1855, p. 37).—The cortical substance, which is perceptible on the

Fig. [illegible].

A lymphatic gland, of the inguinal region of man, double the actual size. *a.* vasa inferentia; *b.* vas efferens coming out of the hilus; *c.* alveoli of the surface of the cortex, seen through the envelope.

whole surface of the gland, except the hilus, forms a soft, juicy layer, with various shades of yellowish-white, reddish-yellow, or reddish-grey, measuring, in large glands, two, two and a half, or even three lines in thickness. Externally, and partly also upon sections, it exhibits a coarsely granular vesicular appearance, almost like *Peyer's* glands that have been exposed from without. This appearance, which was well known to the older anatomists, is produced by a great number of greyish round bodies like follicles, surrounded by narrow whitish borders. If the structure of the cortex be more narrowly inspected, it is easily seen that the supposed follicles are not separate structures, like the elements of a *Peyer's* patch, or of a tonsil; and it appears, indeed, that they cannot be isolated from one another at all. The appearance of follicles will be found to result from projections, in every direction, of portions of the cortical substance, which are contained in the compartments of a pretty regular frame-work. This frame-work arises by a great number of thinner and thicker laminæ (0·004‴ to 0·02‴ and upwards), from the inner surface of the envelope; the laminæ being so regularly connected with each other as to form a fibrous network, extending through the whole cortex; the roundish polygonal spaces of this network may be called the *alveoli* of the lymphatic glands, and they measure from $\frac{1}{8}$‴ to $\frac{1}{3}$‴ in diameter. In man, these alveoli are most regular in the outermost layer of the cortex, and are here for the most part distinct from each other; perhaps even entirely separate, but this is difficult to determine; whilst further inwards, the septa between the alveoli are frequently less complete and more delicate. At least as we approach the interior, the septa become still finer, and the alveoli are no longer completely shut off from each other, so that the cortical substance here obtains a somewhat homogeneous appearance.

Fig. 208.

Section of the cortical substance of a human inguinal gland; magnified 80 times. *a*. envelope of the gland; *b*. four superficial vasa inferentia; *c*. larger alveoli of the surface of the cortex, with the fine meshwork in their interior; some with their contents; *d*. smaller lacunæ situated further inwards; *e*. partitions of the alveoli.

With regard to the intimate structure of the cortex, the partitions consist for the most part of ordinary fibrous connective tissue, with some few fine elastic elements; and besides these, there occur a variety of structures very similar to the plasma-cells of *Virchow*; which I regard as nothing else than young connective tissue. The structures in question are delicate fusiform fibres, whose average length is 0·02‴, with narrow cell-bodies, which give off fine processes, and contain a small, short, elongated nucleus; others of these structures have three of these processes, and they all behave towards alkalies and acetic acid more like connective tissue, and present nothing of the resistance of plasma-cells. These fibrous elements do not lie scattered in the partitions, but rather are grouped into large collections, and they not unfrequently form by themselves the more delicate trabeculæ. Not unfrequently, also, on teasing out a washed section of the cortical substance, we may distinctly observe them to be connected by their processes, and they may be cleansed accordingly, as a special modification of what I have termed the 'reticulate connective tissue.'

The contents of the alveoli of the cortical substance consist of a greyish-white pulp of alkaline reaction, which appears entirely to agree with that of the follicles of the tonsils. In fact, even microscopical examination, as microscopists unanimously assert, detects at first sight nothing but a certain quantity of fluid, with numerous morphological elements. But when this pulp is examined more closely, it is seen to be traversed by a rich capillary network, first indicated by myself (*Handb. d. Geweb.*, 1 aufl., 1852, p. 562); so that it comes, indeed, to present an appearance like that pointed out by *Ernst*, *Frei* and myself, as characterising the follicles of *Peyer's* glands, or the Malpighian corpuscles of the spleen. I find reason, however, from further study of the lymphatic glands, to agree with *Donders*, in regarding the composition of the contents of these alveoli as quite peculiar. Hitherto we have regarded these alveoli as simple cavities, filled by a connected mass of cells and nuclei, but the true structure would appear to be essentially different from this; each alveolus proves to be traversed by a very great number of trabeculæ, mostly very delicate, with fibrils and laminæ which anastomose in various ways with each other, and form a beautiful spongy tissue, which most resembles, of course in miniature, that of the spleen. The microscopical structure of this spongy tissue is extremely beautiful; and I have observed it nowhere else in the adult. Besides the vessels which are distributed to the alveoli, and which are supported on the larger trabeculæ, this tissue consists simply and entirely of the above-described fusiform and stellate fibre-cells, which simply anastomose with each other where the spongy tissue is most delicate; and where it is somewhat coarser, several of them lie side by side to form the thicker trabeculæ.

Now the juice which is readily obtained from the cortex of a lymphatic gland, is contained in the anastomosing meshes of the above-mentioned delicate spongy tissue. To the microscope it presents nothing else than roundish cells, 0·003‴ to 0·004‴, more rarely reaching 0·005‴ to 0·007‴, which entirely agree with those of the chyle and lymph. My more recent observations lead me to reject the belief, that this juice is an independent stationary gland-element, and I now view it as being simply chyle or lymph, which is continually carried towards the vasa efferentia. But this theory will be discussed more in detail further on.

The medullary substance occupies the interior of the glands, and is more or less exposed to view at the hilus, according to the extent of this spot. Its colour, in the glands of the external parts, is whitish, but in the visceral lymphatic glands is more reddish-grey. In man it is more or less sharply marked off from the cortical part, and does not present any trace of the alveolar structure of the cortex, but consists of a dense plexus of *lymphatic vessels*, which is in immediate connection with the vasa efferentia of the glands; and here also the coarser ramifications of the blood-vessels are found. Both kinds of vessels are supported by a pretty abundant stroma of rather dense connective tissue, without elastic elements; and in this stroma in the larger glands of the external regions, larger or smaller collections of fat-cells are interspersed.

The most difficult part of the anatomy of the lymphatic glands, is to ascertain the arrangement of the lymphatic vessels in their interior, and the two old views of *Malpighi* and *Hewson* still stand opposed to each other. The former of these authors regarded the glands as consisting of large anastomosing spaces (or *cells*, as they have been termed); the latter, on the other hand, considered them as a plexus of true lymphatic vessels. For my own part, I find a great difference, which has not been noticed by any physiologist, between the condition of the lymphatic vessels in the cortex and in the medulla of the glands. In the former situation, it is readily seen how the different vessels on their arrival at a gland repeatedly divide and perforate the envelope of the organ; they then surround the outermost alveoli of the cortex with still finer, more rectangular and radiating twigs, and dip into the septa of connective tissue. Thus far the afferent lymphatics are easily traced, but it is extremely difficult to follow them in their further course inwards. After repeated and continuous study of these organs, I find reason to adhere to the opinion, expressed in the first edition of my German handbook, and confirmed by the recent statements of *Ludwig* and *Noll*, to the effect that the finest branches of the vasa inferentia open into the alveoli of the cortex, inasmuch as in successful injections from the vessels in question, first the alveoli, and then the vessels of the medulla and the vasa efferentia become filled. But, on consideration of our more advanced knowledge of the contents of the alveoli, I would add to this opinion, that the interior of the alveoli is not to be considered as a simple large space traversed by the lymph, but rather as a *corpus cavernosum lymphaticum*, if we may venture to give it such a name. With respect to the mode of connection of the finest vasa inferentia with the spongy tissue of the alveoli, I have not yet been able to obtain any microscopical data, yet I do not believe that this circumstance constitutes a valid reason for relinquishing the assumption, which is supported by so numerous other facts, that the vasa inferentia open into the mesh-work of the alveoli. Has any one even in the corpora cavernosa of the sexual organs, been able directly to observe the connection of the arteries and of the venous spaces? Yet here the tissue is not nearly so delicate, and all the conditions are much more easy of investigation than in the lymphatic glands. Of the circulation of the lymph in these glands, I can only affirm that the finest branches of the vasa inferentia are seen to be true vessels, 0·008‴ to 0·01‴ broad, of the structure of the larger capillaries of the blood-vascular system; on microscopical investigation of the cortex, they not unfrequently come to view, and are readily distinguished from the blood-vessels by the colourless cells filling them. Again, I have satisfied myself that the alveoli contain no lymphatic vessels; and lastly, that the numerous cells and nuclei contained in them do undoubtedly lie free in the mesh-work. Now, if we also take into account the results of injections, I think we shall be warranted in assuming, that the vasa inferentia in man, after they have become attenuated to the size mentioned, open freely into the spongy tissue of the alveoli; and that this tissue, from its possessing no trace of epithelial lining in its spaces, is to be regarded as a true *lacunar system*.

On the relation of the spongy tissue of the cortex to the inferent lymphatic vessels, I would further remark, that all our knowledge of this subject leads us to regard the outermost and most sharply defined alveoli as being less frequently and less directly connected with the vasa inferentia, than those which are situated in the more internal parts of the medulla. At least in the mesenteric glands, both of man and animals, at the period of absorption, when all the inferent vessels contain a whitish juice, the outermost alveoli are seen not to be milk-white, but of their ordinary grey colour, while the inner parts are frequently whitish throughout. To this condition, however, more recent observations have taught me that there are exceptions, for I have seen two cases in man, in which the mesenteric glands were coloured milk-white quite equally on the surface and medulla, the colour being in patches of various sizes. When, moreover, it is considered, that in injections of the vasa inferentia, even the outermost alveoli become filled, we cannot resist the assumption, that they do really communicate with those vessels.

Fig. 209.

Transverse section of the mesenteric gland of the ox, magnified 8 times. *a.* hilus of the gland; *b.* medullary substance, with fine networks of lymphatic vessels; *c.* cortical substance, with indistinct alveoli; *d.* envelope of the organ.

It is relatively easy to follow the lymphatic vessels in the medullary substance. Even with the naked eye, sections of this substance exhibit, besides blood-vessels, a spongy tissue, from which, in the fresh gland, we may readily press out small drops of fluid, which is either milky or serous, according as the gland contains chyle or lymph. Injections, too, particularly from the vasa efferentia, or fine sections microscopically examined, distinctly show that the medullary substance consists for the most part of a dense plexus of coarser and finer lymphatics, which, at least in the number of of their anastomoses, resemble the vascular system of the corpora cavernosa. This spongy tissue, however, is very essentially distinguished from that of the sexual organs, by the circumstance that the lymphatics composing it are all provided with special coats, and can even be isolated, at least in part, from the stroma of connective tissue which supports them. The more intimate condition of the lymphatic plexus of the medullary substance is as follows: Emerging everywhere in great numbers from the inner parts of the cortex, fine lymphatic vessels enter the medulla, and immediately anastomose freely with each other, and become gradually wider and wider in their course towards the centre, and towards the hilus of the gland. Here they unite with each other by degrees to form the wide vas lymphaticum efferens, which is either single or multiple. This vessel, accordingly, is not related to the glandular parenchyma at all in the same way as the vasa afferentia, as has hitherto been universally assumed; indeed it has nothing to do with the cortical substance, and in all the larger glands with a well-formed hilus, it passes directly from the hilus without ever coming in contact with the cortical substance. The course of the chyle-vessels in a lymphatic gland is, therefore, the following: The vasa efferentia pass from many peripheral points to the convex side of the gland, and, entering the cortical substance, pass into the lacunar system of the alveoli, the spaces of which are to be regarded as the continuation of the vessels. Thence, provided anew with walls, the lymphatics pass into the medullary substance, and here produce a rich plexus, from which, lastly, one or more vasa efferentia emerge, and leave the gland directly through the hilus.—With regard to the *structure* and *width* of the vessels of the medullary substance, it is still to be remarked, that they all possess an epithelium of elongated cells, a distinct tunica intima, consisting of connective tissue with interspersed nuclei (plasmatic cells?). The tunica media of the lymphatics is here composed of smooth muscular fibres, which are easily recognised, and appear to have an exclusively transverse direction: the tunica adventitia is replaced by the connective tissue, which forms the stroma of the medullary substance. In microscopical sections, these vessels are very easily distinguished from the arteries of the medulla by the absence of the elastic inner coat, and the slighter development of the muscular fibres; while the veins, even down to the fine twigs, are characterised by an abundant intermixture of fine elastic fibrils, which are totally absent even in the large lymphatic vessels of the medulla.—The width of the lymphatics of the medulla varies from $\frac{1}{3}'''$ to $\frac{1}{2}'''$; close at the origin of the vasa efferentia they measure only $\frac{1}{10}'''$, $\frac{1}{20}'''$, or even $\frac{1}{50}'''$, and this small diameter is maintained as the vessels approach the cortex.

The arteries of the lymphatic glands are mostly multiple. The largest always passes through the hilus into the interior of the gland, and is frequently joined by others which run to the medulla, either alone or by the side of small vasa efferentia, which leave the gland at other depressed spots resembling hiluses. In the medulla, a coarser ramification of these vessels is formed by all the main branches of them proceeding to the several parts of the cortex, while a very spare capillary network of separate scanty twigs is alone found around the medullary lymphatic vessels. It is in the cortex that the proper terminal ramification of the arteries takes place. Here the vessels, after leaving the medulla, first run in the partitions of connective tissue between the alveoli, and then, penetrating into their interior, produce a rich capillary network, with relatively wide meshes, in the delicate trabecular network contained in them: in the formation of this plexus, at least in large glands, numerous other small arteries are concerned, which enter the cortex directly from without. The veins present, upon the whole, the same condition as the arteries, only their trunks are less numerous, and are frequently limited to a single large vessel emerging from the hilus. The width of this vein is remarkable, and it often reaches a diameter double that of the corresponding arterial trunk.

The lymphatic glands, at least the large ones, I have found to possess habitually some fine nerves, with fine primitive fibres: they enter along with the arteries, and are lost to view in the medulla. The ganglia mentioned by *Schaffner (Zeitschr. f. rat. Med.* vii. 177), in the lymphatic glands, I have not yet seen, nor is the description of them by this author exactly of the kind to awaken much confidence.

In conclusion, to sum up the anatomical condition of the lymphatic glands, we may state: that they are not to be in any case regarded simply as a plexus, however dense, of lymphatic vessels. The sharp limitation of the organ, its special investment, the abundant stroma of connective tissue traversing it, and the numerous blood-vessels which supply it, are circumstances which even taken by themselves, would give to the gland a claim to a special position of its own, even if the lymphatic vessels in the interior were simply connected with each other after the manner of a rete mirabile. But when we find that these, although arranged in the medulla after the manner of an ordinary plexus, yet present in the cortical substance quite a peculiar condition, such as is nowhere found in the most complicated vascular coils, it is certainly warrantable to regard the lymphatic glands as organs *sui generis*, and not as a plexus of lymphatic vessels. The peculiarity of the cortical substance is owing to two circumstances, first, that the lymphatic vessels here lose their special walls, and are replaced by a system of freely communicating lacunæ; and secondly, that the fibrous and trabecular tissue forming these lacunæ, is traversed by numerous blood-capillaries. In other words, the lymph or the chyle in the alveoli of the cortical substance, flows free through a meshwork formed by blood-vessels and their supporting connective tissue, so that the chyle and blood enter into a much more intimate mutual action than in any other part, the blood-vessels giving off materials to the chyle, and probably taking up in return other substances from it. The great retardation of the chyle, moreover, which must necessarily take place in the meshwork of the cortex, may allow of the substances separated from the blood-vessels becoming further organised, even within the cortex; and this appears to me to constitute an additional reason for regarding the structural conditions of the organs as truly 'glandular,' and therefore their designation of lymphatic glands may be very properly retained.

A critical examination of the recent statements of *Ludwig*, *Noll*, *Gerlach*, *Brücke* and *Donders*, on the structure of the lymphatic glands, will be found in my *Micr. Anat.* ii., 2, pp. 539—544.

With regard to the physiological condition of the lymphatic glands, I may append the following remarks. Belonging to the same series as the 'vascular glands,' we have so recently become acquainted with the true structure of the lymphatic glands, that we are scarcely yet in a position to form reliable hypotheses as to their function. I shall state in brief what I venture to regard as the most important point in their physiology. The chief function of the lymphatic glands appears to be the formation in them of the great majority of the chyle and lymph-corpuscles. It is a long known fact, that the chyle beyond the glands towards the thoracic duct, is richer in cell-elements than in the lymphatic vessels between their origin and their glands; and it has, accordingly, been supposed by many writers, that the glands have an influence in the production of these cells; but no one has ventured to lay stress upon this circumstance, because it has been hitherto impossible to give precise information as to the manner and locality of their origin. But the significance of the lymphatic glands in the process of blood-formation was much confirmed, when, some years ago, *Virchow* gave to the world his excellent treatises on Leucæmia, and brought forward cases where an increase of the colourless elements of the blood was met with as a coincidence of simple hypertrophy of the lymphatic glands (*Arch.* i., p. 571). Since that time, this important function of the glands has obtained wider recognition, and has been confirmed and illustrated by various authors (*Bennet* and others). Still the anatomical relations of parts in the normal gland had not been demonstrated, so that *Virchow's* hypothesis, that the lymphatic glands were the seat of a process of blood-formation, though it threw much light on his cases, yet was not supported on a firm physiological basis. Such anatomical proof, however, has now been given; and supported upon it, *Brücke*, *Donders* and myself have expressed ourselves unanimously in favour of the hypothesis, that the elements of the lymphatic glands go over into the chyle and lymph. Having regard to all the facts mentioned in this paragraph, I am of opinion that the tissue of the cortical substance is to be regarded as the proper place of formation of the lymph-corpuscles, though I do not mean to deny that similar processes may take place in the medulla also. In the alveoli of the cortex, with their peculiar anatomical arrangements, the entering lymph comes most intimately into contact with the numerous blood-vessels. Now since the pressure to which the blood is subjected is, in any case, much more considerable than that which is exerted upon the lymph, many constituents of the blood will pass out here into the lymphatic lacunæ and mingle with the lymph; and as the lymph in this lacunar system is meanwhile moving very slowly, every opportunity is given for the formation of cells. The exudation from the blood-vessels obviously plays a much more important part in this process, than the slow movement of the juice itself, and I am of opinion, that if the former were removed the multiplication of the lymph-corpuscles in the glands would not be considerable. For when we consider that the lymph from vessels which have not passed through glands is always very poor in corpuscles, no matter whether it has gone over a short or long distance; and again, that the lymph of those vertebrate animals which possess only a few isolated lymphatic glands, or none at all, is very poor in cells, we shall arrive at the conviction, that the lymph is of itself but little capable of organisation, even when it has gone over a considerable distance, and that the formation of the colourless cells in the lymphatic glands is chiefly dependent upon the transuding constituents of the blood. The processes, therefore, in the lymphatic glands may more correctly be expressed by saying that a continual exudation of certain constituents of the blood takes place from the blood-vessels into the lymphatic lacunæ, and from this there results an abundant formation of cells which fill the lacunæ. The entering lymph with its scanty cells now become mingled with the corpuscles produced in the gland, and flowing through the cortex into the medulla and vasa efferentia, takes with it a part of the cells formed in the cortical spaces; and these cells are continually reproduced. This would appear to be the more correct account, because we cannot imagine that the whole mass of cells of the cortical alveoli moves onwards with the same celerity as the entering chyle, for in that case the vasa efferentia must contain far more cells than they actually do. From this statement it will be seen, that I regard the contents of the alveoli as being for the most part independent of the entering lymph for their formation; and if these contents are not stationary, yet at least they are not so varying in their condition as the lymph in the afferent vessels: so that, even from a physiological point of view, it appears wholly incorrect to consider the lymphatic glands as being merely plexuses of lymphatic vessels.

The lymphatic glands are subject to numerous *degenerations*. The most frequent are effusions of blood into the alveoli, or pigmentary deposits as the result of these, which may advance so far that the glands become reddish-brown or even black, the bronchial glands especially. They are also subject to thickening of their envelope and of the internal septa, to depositions of fat in their blood-vessels, to hypertrophy with uniform increase of all their parts; and lastly, they are the seat of *tubercle* and *cancer*.

IV.—Of the Blood and the Lymph.

§ 219. All the divisions of the vascular system contain in their cavities a special liquid, which consists of a fluid portion containing numerous morphological particles. According to the colour of this liquid, its occurrence in one or another section of the vascular system and its other properties, it is distinguished into *white* and *red blood*; in other words, into lymph or chyle on the one hand, and blood in the stricter sense on the other. Upon Histology devolves only the description of the elementary forms existing in these fluids, among which the blood and lymph-corpuscles are by far the most important. The description of the other conditions must be left to Physiology.

§ 220. The *Lymph* and the *Chyle* consist, like the blood, of a plasma, which coagulates on leaving the vessels, and of morphological elements; viz., of elementary granules, nuclei, colourless cells, and red blood-corpuscles: all these elements, however, are not to be found in all parts of the lymphatic vascular system, and not everywhere in equal numbers. The *elementary granules* are immeasurably fine granules, which, as *H. Müller* has shown, consist of fat and an envelope of protein. They are contained in enormous numbers in the milk-white chyle, in which they alone produce the characteristic colour; while, in the more colourless lymph, they are either totally absent or appear only in small numbers, and isolated. The *nuclei* are of 0·001‴ to 0·002‴ in size, and more homogeneous in appearance; they often have a vesicular aspect, becoming granular on the addition of water. According to my more recent observations, these nuclei all belong to small cells, and only become free through the bursting of these cells on the addition of water. The *colourless cells*, the *chyle* and *lymph-corpuscles* of authors, occur almost everywhere in the system of lymphatic vessels in considerable numbers, and completely agree with each other in the chyle and in the lymph. They are round cells, measuring from

Fig. 210.

Elements of the chyle. *a*, lymph-corpuscles which have become stellate by the passing out of the contents; *b*, small cells with indistinct nucleus; *c*, three cells with distinct nuclei; *d*, two large cells with nuclei; *e*, granular cell with indistinct nucleus.

0·0025‴ to 0·0055‴ in size, and when examined in their native fluid, appear homogeneous or granular, and contain a homogeneous nucleus, generally indistinct, but slightly shining. The addition of water changes their appearance, the nucleus and other contents becoming turbid from the deposition of a granular precipitate; they are rendered quite transparent and pale by acetic acid, and their nucleus is then seen very distinctly, diminished in size and strongly granular in appearance: or they even burst and discharge their contents, and this change is frequently also effected by water, particularly in the smaller cells, a transudation of clear drops of albumen having previously taken place. As the lymph-cells are spherical, dilute solutions occasion no very perceptible alterations of form; but, on the other hand, evaporation of the fluid and concentrated solutions produce a considerable diminution in their bulk, and frequently also give them a dentated appearance (fig. 210, *a*). The remarkable phenomena of contraction in the white corpuscles, in consequence of which they assume various toothed forms up to an actually stellate form, were first indicated by *Wharton Jones* (see § 15); and it is now pretty generally believed that these appearances belong to the cells as living organisms.

The *size, number* and *form* of the lymph-corpuscles is somewhat different in different places. In the commencements of the chyle-vessels (which are particularly well adapted for such investigations), and in the mesenteric lymphatics before they enter the lymphatic glands, the chyle contains but few chyle-corpuscles, and, in the smallest mesenteric vessels, which we are able to see there, are frequently quite absent. In the larger trunks, however, they are always present; and here they generally appear as small corpuscles, measuring 0·002‴ to 0·003‴ in diameter, with an envelope which closely surrounds the small nucleus, and often appear in the act of development, as if by the apposition of granules. After the chyle has passed through the mesenteric glands, the cells are more numerous and larger, so that, in the chyle-vessels at the root of the mesentery (as well as in the larger lymphatic trunks), numerous larger cells are found, measuring up to 0·0055‴, along with smaller ones of the same kind as those just described. Simultaneously with this increase in size and number, a more or less distinct multiplication of the lymph-corpuscles by a process of partition is seen to take place, at least in dogs, cats and rabbits. This is effected by the larger cells becoming elongated, reaching 0·006‴ and 0·008‴ in diameter, and then, after partition of the nucleus, breaking up into two parts by a circular middle constriction. This process is almost entirely absent in the thoracic duct, and the larger cells, 0·004‴ to 0·0055‴, are accordingly scanty in this situation. The great majority of the cells in this duct, at least in animals, are always larger than the blood-cells (0·0025‴ to 0·0035‴); while, on the other hand, in man, as they were observed by *Virchow* and myself in an executed criminal, they were invariably smaller (0·002‴ on an average). The nuclei of these lymph-corpuscles, which are imperfectly seen without the addition of acetic acid, were found in this case to be mostly simple and round, occasionally also notched, or shaped like a horse-shoe, or like a biscuit; they were very rarely truly multiple. In the lower mammalia, cells with nuclei breaking up by means of acetic acid, or constricted and multiple from their origin, are very rare, apart from those in the act of dividing, yet they are occasionally found (divided into three to five parts), and sometimes in large numbers.

I have not yet observed red blood-corpuscles in normal human chyle; but it is to be noticed that they are almost always found in small numbers in the thoracic duct of animals, and also occasionally in the lymph of certain organs, as the spleen. Since they do not exhibit the slightest trace of development within the lymphatic vessels, I regard them as elements which have escaped from the blood-vessels. So long as no direct communication of the two vascular systems in the peripheral parts is demonstrated, I am of opinion, that this passage is effected only accidentally in consequence of ruptures of fine vessels, a circumstance which can be easily understood to take place in the peculiar structure of certain organs, such as the spleen and lymphatic glands. Indeed, as I have shown in tadpoles, this accidental passage may actually be directly observed.—I may, however, remark, that I have not unfrequently found in the chyle of the larger vessels, round *granular cells* of a brown colour, 0·004‴ to 0·005‴, which entirely correspond with those to be presently described as resulting from the blood, and which probably come from the lymphatic glands.

From the facts before mentioned, and from the statements of § 218, it cannot be considered doubtful that the lymph-corpuscles have their origin chiefly from the lymphatic glands, in which they are being constantly reproduced by a progressive multiplication of the cells of the alveoli, in proportion as they are carried off by the efferent vessels. As for the cells in the commencement of the vessels, we may agree with *Brücke* in ascribing their origin, in the intestine at least, to the glandular follicles of this part, the solitary glands and the glands of *Peyer*: in favour of this belief may be stated the circumstance observed by myself, that the chyle-vessels coming from *Peyer's* patches are more abundantly provided with cells. Lymphatic vessels which have no connexion with glands, either contain no cells at all, according to my observations (lymphatics of dog's liver and tadpole's tail), or only a very few, as the lymphatics of the spermatic cord of the ox, and those of the surface of the spleen. In such cases as the last, unless we are content to believe in a free production of cells, a hypothesis which has been shown in the general part of this work to be untenable, we can only regard the scanty lymph-corpuscles as being the epithelial cells of the smaller vessels, which give rise to the appearance of morphological elements in the lymph, either by a normal multiplication or by an accidental partition of their cells. A similar process of formation of lymph-corpuscles must explain the multiplication of the cells, which is occasionally witnessed in the lymphatic vessels between the glands and the thoracic duct. The entire mass of corpuscles existing in the lymph, compared with that of the blood-corpuscles in the blood, is very inconsiderable; not only in the medium-sized and smaller trunks of the lymphatic vessels, but even in the thoracic duct their numbers do not approach in the remotest degree to those of the blood, as even in this situation all the elements of the lymph can be inspected without dilution. Accurate enumerations have, however, not yet been made; and it can only be stated, that here, too, a considerable variation exists, and that a milk-white chyle is not always rich in corpuscles.

§ 221. *Of the Blood.*—The blood, so long as it circulates in the vessels, is a slightly glutinous fluid in which only two elements are to be distinguished, the blood-corpuscles, blood-globules, or blood-cells, chiefly red but partly colourless (*corpuscula s. globuli s. cellulæ sanguinis*), and the colourless fluid portion, the *liquor s. plasma sanguinis.* After it has left the circulation, the blood generally coagulates completely by the solidification of the fibrine dissolved in its plasma, and afterwards separates by the contraction of the coagulated fibrine into a solid and liquid portion, the *crassamentum* and the *serum.* The former is intensely red, and contains, besides the fibrine, almost all the coloured, and the majority of the colourless blood-globules, with some of the constituents of the plasma which remain in solution; while the remainder of this plasma, together with some colourless blood-corpuscles, forms the serum. In certain cases, which in the human subject occur especially in diseases, the coloured globules sunk more or less below the surface of the fluid before coagulation takes place, and then the crassamentum has a superficial colourless or whitish stratum (*crusta phlogistica*), which consists only of coagulated fibrine and colourless blood-cells, together with the fluid saturating them.

Fig. 211.

Human blood-globules. *a.* seen from the surface; *b.* from the side; *c.* united in rouleaux; *d.* rendered spherical by water; *e.* decolourised by the same; *f.* blood-globules shrunk by evaporation.

The coloured or red blood-globules, also called merely *blood-globules*, which alone convey the red colouring matter of the blood, are small, non-nucleated cells, of the form of flattened lenses, and are contained in the blood in such enormous numbers, that we cannot readily investigate their minute characters without dilution, and they appear, so to speak, to constitute the entire mass of the blood. Important as it might be to know the proportion of the blood-globules to the plasma, and their exact number and volume, yet all our investigations have been frustrated, till a short time ago, by the difficulty of the subject. Even now the statements of *Schmidt*, according to which forty-seven to fifty-four parts of moist blood-globules are contained in one hundred parts of human blood, can only be designated as approximative. There is only one method that is suited for the attainment of this object, namely, the direct enumeration of the blood-globules in accurately determined quantities of a given specimen of blood; and with this we need to determine as accurately as possible, the volume of the individual blood-corpuscles (*Vierordt*), but hitherto the first point only has been practically carried out. *Vierordt*, the meritorious deviser of this method, counted in his own blood 5,055,000 blood-cells in 1 cub. millimetre; *Welcker*, who somewhat modified *Vierordt's* proceeding, enumerated as an average, 5,000,000 in the male, 4,500,000 in women. In the latter sex, however, it appears that the number is still further reduced during pregnancy, and in suppression of the menses. These variations may be easily understood, and the more so, as *Vierordt* has lately shown (*Arch. f. Physiol. Heilk.*, xiii., p. 260), that in animals the number of the blood-cells varies in the ratio of even one to three.

The red blood-globules, when examined individually, present the following structure: Their form is mostly that of a bi-concave or flat circular disc, with rounded margins, and they accordingly appear to the observer to vary in shape according as their surfaces or their sides are directed towards him. In the former case, they are pale-yellow, circular corpuscles, which almost always have a slight central depression, and this sometimes has the aspect of a clear central spot, sometimes of a dark central body, according as the corpuscle is in or out of the focus of the microscope; the appearance in the latter case is apt to be confounded with that of a nucleus. When seen from the side, however, the blood-corpuscles show themselves as dark rod-shaped structures, of the form of an elongated narrow ellipse, or like a biscuit seen edgewise. With regard to their intimate structure, every blood-globule consists of a very delicate, yet tolerably firm and elastic, colourless cell-membrane, composed chemically of a protein substance nearly allied to fibrine: contained in this envelope is a viscid coloured substance, which in the separate blood-globules appears yellow, and is composed principally of globuline and hæmatine. In the adult, the contents of the blood-globule present no trace of morphological particles, of granules, or of a cell-nucleus; they are accordingly true vesicles, and on this account, as well as from their shape not being globular, the name of 'blood-cells' is to be preferred. The elasticity, softness, and pliability of their envelope is so considerable, that they are enabled to accommodate themselves to vessels which are narrower than their own diameter; and for the same reason, when they are elongated, flattened, or otherwise altered in form by pressure under the microscope, they are able to reassume their previous shape. The blood-globules are rendered the more capable of adapting themselves to the vessels, by the fact that their surface is quite smooth and slippery, so that they easily glide along the similarly-constructed walls of even the narrowest capillaries.

The size of the blood-globules is subject to alterations in different individuals, which are not of very inconsiderable amount, when we take into account the smallness of the corpuscles with which we have to do. Their average breadth is 0·0033‴ ($\frac{1}{300}$‴), and their average thickness, 0·00062‴. These dimensions vary within certain limits, but it appears that at least ninety-five out of every hundred corpuscles are of the same size. We have few data as to their alteration in size under different circumstances in the same individual, but *Harting* states that their average dimensions are less after a full meal (by about 0·00013‴), and that more remarkable extremes of size are then observed.—With regard to the number of the blood-globules, we may venture to draw some general conclusions from what we know of the amount of solid constituents in them: that they are present in larger quantity in the male than in the female sex; further, that after repeated venesections, and after prolonged abstinence, they decrease in number; and that in certain diseases, as chlorosis and anæmia, they are much more scanty than usual.—The blood-globules, compared with the other constituents of the blood, are *heavier* than the serum and the plasma. In the serum, and in the defibrinated blood, they form a red sediment on standing, while in the plasma they do not generally sink below the surface of the fluid, on account of its quick coagulation. This sinking of the blood-cells, which takes place more slowly or more quickly, according to their own density and to that of the fluid in which they are suspended, may be promoted by their mutual *cohesion*, which is especially observable in inflammatory blood: here, owing to the quick precipitation of the blood-cells, a part of the blood coagulates colourless; but the same phenomenon also occurs in quite healthy blood, and, indeed, may be observed very constantly in the small drops which come from slight cuts of the skin, and frequently also in the blood of venesection. In such cases, the blood-globules are applied to each other by their flat surfaces, and form, as it were, little columns or rouleaux, at the side of which other similar rouleaux may be applied, so that very complicated branched figures may result, or even a system of networks covering the whole field of the microscope (fig. 211, *c*).

Besides the coloured elements, a certain number of uncoloured particles occur in the blood. These are of two kinds: elementary granules of a fatty nature, and real cells. The former, which completely agree with the fat granules of the chyle (see § 220), occur to a very variable extent, sometimes being entirely absent or in very small numbers, sometimes in larger, or, it may be, in enormous amount, so that they communicate to the serum a whitish or even milk-white colour. From all that we know, these must be present every time fat is introduced into the blood by the chyle; and, therefore, even in ordinary alimentation they must enter the circulation in three to six hours, or longer, after the taking of food; yet, in many cases, they seem to disappear in the pulmonary circulation; at any rate *Nasse* (see WAGNER's *Handw.* i., p. 126) and others, have never observed them in the systemic blood of healthy people, and this is a statement which I can confirm as regards my own blood. On the other hand, in herbivora and in sucking animals, and in the goose, the occurrence of these molecules appears to be constant: in pregnant females also, and after the abundant use of milk or brandy, as well as in persons who are fasting (in consequence of the absorbed fat of the body), these fat granules appear to be very frequent, if not a constant constituent of the blood.—The colourless cells or *colourless blood-corpuscles* come from the chyle, and may, therefore, also be called *chyle* or *lymph-corpuscles* of the blood. Some of them have but one nucleus, and completely agree with the small cellular elements of the chyle; others have several nuclei, and measure as much as 0·005‴ in average size; and in this case they generally bear such a marked resemblance to the corpuscles of pus, that it is quite impossible to distinguish the two structures from each other. The larger corpuscles are rarely so granular as the smaller, being usually pretty homogeneous, and their contents are frequently so transparent that their two or three roundish small nuclei can be seen without further trouble. If this is not the case, acetic acid or water brings the nuclei distinctly into view by rendering the contents clear; and in this case, the contents occasionally pass out of the bursting cells in the form of drops; at the same time, especially when acetic acid is used, the nuclei often break up to a further extent, and become converted into irregularly notched and constricted bodies, or even become resolved into a greater number, four, five, six, or more, of small granules while at the same time they acquire an indistinct yellow colour, and the cell-membranes gradually disappear. The other reactions of these colourless blood-corpuscles are those of ordinary cells, without anything characteristic. The number of the white blood-corpuscles has been found by all observations hitherto made, to be somewhat variable. *Moleschott* found the proportion of the colourless to the coloured cells to average 1:335 (2·8 in the 1,000); *Marfels* gives the proportion at 1:309; *Hirt* finds it 1:1761, during fasting, and that it varies after the taking of nourishment between 1:695 and 1:429; *De Pury* gives the proportion as between 1:290 and 1:500. The number is found below the average in fasting persons, non-menstruating females, and in aged individuals. The average number of white globules is found in the blood of young men when their diet is deficient in albumen. It is

Fig. 212.

Colourless blood-corpuscles, or lymph-corpuscles of the blood. *a*, *b*. smaller cells, such as also occur in the thoracic duct, seen from the surface (*a*), and on the side (*b*); *c*, *c*. the same with a visible nucleus; *d*, *d*. large cells originally with multiple nuclei; *e*, *e*. the same after the action of acetic acid, with breaking down or broken down nucleus.

above the average in men and youths after a diet rich in albumen (they then reach to 3·5 in a 1000), in pregnant females (3·6), menstruating women (4·0), and in boys (4·5). In fasting animals, as *Heumann* has also observed in pigeons, they decrease; and after long fasting they even disappear entirely, at least in frogs, though, on the other hand, *De Pury* found their relative numbers to be increased after three weeks of low diet and fasting. Very remarkable is their increase in numbers, not only relatively but absolutely, after venesections, and this may go to such a length in the case of the horse (of course after enormous evacuations of blood, up to fifty pounds), that the coloured and colourless corpuscles appear equally numerous.—The colourless corpuscles are lighter than the coloured, and are, accordingly, found in greater quantities in the upper strata of the crassamentum. If the latter possesses a buffy coat, a large number of such corpuscles are always found in it, especially when their number in the blood has been increased by previous venesections; hence, in such cases, they may even constitute the half of the buffy coat (*Remak*, *Donders*). Their small tendency to sink partly results also from the circumstance, that, although they are provided with uneven surfaces and are disposed to cohere to each other, they nevertheless rarely form any large heaps, and never rouleaux. In leucæmia, the colourless blood-cells are remarkably increased in number, so that they have been found by *De Pury* in the proportion of one to only seven to twenty-one of the red corpuscles. In ague, even though there be enlargement of the spleen, *Hirt* finds the colourless cells reduced in amount. By the operation of tonic remedies (myrrh, iron, quinine), the number of the colourless cells may be notably increased, according to *Hirt*, even in half an hour.

Conditions of the Blood-corpuscles in different kinds of Blood.—Sensitive as the blood-cells are to different re-agents outside the body, their appearance within it is remarkably constant, at least as regards their *form*. Within the limits of physiological conditions, no considerable and permanent differences of them are to be detected; in the arterial and venous blood, and in various sorts of blood in different organs, they exhibit an almost uniform aspect: and not only is this the case, but even in the most diverse diseases no visible alterations present themselves. And yet it cannot be doubted that the forms of the blood-cells, like the colour and chemical composition of the blood, are subject to certain variations and changes, according as the blood is more concentrated or diluted, and according as it contains more or less of certain salts and other substances. This change of form, however, is so trifling, that it is not surprising that it has not yet been recognised with certainty. At any rate, I must add my positive testimony to that of *Henle*, that all those well-marked forms, the jagged blood-corpuscles on the one hand, and the diminished spherical ones, coloured or discoloured, on the other hand, are never met with in the circulating blood. It is not, indeed, impossible that slight degrees of flattening and swelling of the blood-corpuscles may hereafter be detected, though it must never be forgotten in such investigations, how quickly the blood-corpuscles alter their forms; and we must be on our guard against regarding as a natural condition, an appearance which has arisen for the first time after the blood has left the circulation.—The *numbers* of blood-cells in different kinds of blood, appear to be subject to more variation than their forms. With regard to the coloured corpuscles, they are somewhat more numerous in venous blood than in that of the arteries. Of the venous blood, that of the hepatic veins stands pre-eminent, containing, according to *Lehmann*, many more blood-cells than the portal blood, and it even exceeds in this respect the blood of the jugular veins, in which also they are numerous above the average. The colourless blood-cells, as has been shown by *Funke* and myself, are present in very large numbers in the blood of the splenic vein. Here they sometimes present one nucleus, sometimes several; according to *Hirt*, the splenic artery contains these cells in the proportion of 1:2200 red ones, while in the vein the proportion is 1:60. The colourless blood-cells are also numerous, according to *Lehmann*, in the blood of the hepatic vein, in which they are distinguished by their very different size. I also have observed this fact in many cases, but by no means always; and I cannot regard it as an exclusive character of the hepatic venous blood, seeing that, even in the portal blood (as *Lehmann*, too, found in one case), and in the blood of the pulmonary veins, I have found the same large number of colourless blood-cells, the animals having been perfectly healthy. Elsewhere also, the colourless cells are more numerous in venous than in arterial blood (*Remak*). In the superior vena cava and iliac vein of the dog, *Zimmermann* observed that these cells had but one nucleus, while in the inferior cava they had several.—On the peculiar large multinucleated colourless cells, and on the biscuit-shaped ones with two nuclei, which occur in the blood of the liver and spleen of young animals see above, § 168.

Many experiments have been made on the influence of various re-agents upon the blood-globules, but some of the results obtained are of very little importance. I shall, therefore, only adduce here, principally from investigations of my own on the blood-globules of man, what may be of use in settling their anatomical and physiological characters. Water renders the blood-globules first spherical, and, owing to the decrease of the horizontal diameter which accompanies increase in thickness, they appear to become smaller (0·002‴ to 0·0024‴), as may be best observed on corpuscles which have united to form rouleaux. Then, generally without any further alteration in size, the colouring matter and other contents are extracted, sometimes slowly, sometimes suddenly by a jerking swelling up of the corpuscles; in this manner the fluid portion of the blood becomes coloured, the corpuscles, on the other hand, appearing as colourless vesicles or rings, so faint, that it is often difficult to detect them. Yet by the addition of tincture of iodine which colours them yellow, or of the reagents which render them smaller, and make their outline more distinct, such as gallic or chromic acid, and various salts (chloride of sodium, nitrate of potass, etc.), they can readily and distinctly be brought into view, and thus it may be shown that water by no means dissolves or destroys them. Acetic acid of 10 per cent. renders the corpuscles extremely pale instantaneously, so that they are scarcely any longer perceptible; but still they are not dissolved, for they may be seen several hours afterwards as delicate rings. A solution of 20 per cent. acts more energetically, and in glacial acetic acid, the cells are found after two hours to be quite dissolved in the greasy brown mass into which the blood is converted by this re-agent. Of all the alkalies, potass acts the most powerfully. A solution of 10 per cent. renders the blood black, and immediately dissolves all the blood-cells, rendering them first spherical and smaller. A solution of 20 per cent. acts in a similar manner, except that a few cells remain behind for some time as pale rings; while, on the other hand, a concentrated solution of two parts potass to one part water, does not attack the corpuscles beyond rendering them extremely small, and then they either remain spherical or become jagged and folded. The blood, as a whole, is coagulated by this solution, and becomes of a brick-red colour, passing on to a bright brownish-red. On the subsequent addition of water, the blood-globules enlarge to 0·006‴, but otherwise appear as if no re-agent had been added, generally remaining flat; they then disappear as in an ordinary dilute solution of potass. The same phenomenon of diminution in size of the blood-cells, which is produced by some of the substances already mentioned, is of very common occurrence on the addition of re-agents, and must be attributed to the abstraction of various substances, especially water, from the blood-cells, seeing that it is always concentrated solutions which act in this manner. In these cases also, from the blood-globules reflecting the light at several points, the colour of the blood becomes brighter, generally brick-red; but the change in hue is not always to the degree exactly corresponding to the shrinking of the cells (*Moleschott*). Even simple concentration of the blood-plasma by evaporation, causes the blood-cells to shrivel more or less, and then they are either converted into round dark shining globules, 0·001‴ to 0·002‴ in size, or into jagged stellate bodies; or, lastly, into variously-curved and folded plates. All concentrated solutions of metallic and other salts act in the same manner, except in those instances, by nitrate of silver, for example, where the corpuscles are immediately destroyed. The hydrochlorates and nitrates of the alkalies act more strongly than the sulphates and phosphates of the same degree of concentration.

When diluted, such salts cause the blood-cells to swell up; and the same effect is sometimes produced by concentrated solutions also.—Lastly, we have to mention the very important influences of oxygen and carbonic acid upon the blood-cells, the absorption of which gases, into the interior of the corpuscles, both in the living subject (in the lungs and systemic capillaries) and in experiments out of the body, is the cause of the different hues exhibited by the blood. This absorption takes place without altering the form of the cells, and the two gases may be applied alternately several times over to the same specimen of blood, without altering the blood-corpuscles in any manner. The gases in question also act in a similar manner upon the isolated colouring matter of the blood as upon the blood-corpuscles (*Magnus*, *Marchand*), and even upon the red blood-crystals. The researches of *Schönbein* and *His*, which show that the contents of the blood-cells have the power of changing oxygen into ozone, afford us a hope that these important relations may soon be better understood than has been possible hitherto.

Blood-corpuscles of other Animals.—The non-nucleated blood-corpuscles of *mammalia* do not differ in form from those of man, except that those of the camel and llama are oval, and 0·0038‴ long; they are mostly smaller than in man, measuring in the dog 0·0031‴; in the rabbit and rat, 0·0028‴; pig, 0·0027‴; horse and ox, 0·0025‴; cat, 0·0024‴; sheep, 0·0022‴. They are smallest in the musk deer (0·00094‴), and only in a few instances are they larger than in man; thus in the elephant they measure 0·005‴.—All the lower classes of vertebrata have almost invariably *oval nucleated* blood-corpuscles of the form of pumpkin-seeds. Those of birds are as much as 0·004‴ to 0·008‴ in length, and have rather roundish nuclei; those of amphibia measure between 0·008‴ to 0·025‴ in length, and have either round or oval nuclei. The blood-cells are largest in the naked amphibia, measuring in the frog, 0·011‴ to 0·013‴ in length, 0·007‴ to 0·008‴ in breadth; in the proteus, 0·025‴ in length, 0·0016‴ in breadth; and in the salamander, 0·02‴ in length: those of fish, lastly, generally measure 0·005‴ to 0·007‴ in length, except those of the plagiostoma, which reach to 0·01‴ to 0·015‴, and those of the lepido-siren, 0·020‴ in length, 0·012‴ in breadth. Those of myxine and petromyzon are 0·005‴ in diameter, round and slightly bi-concave. Leptocephalus has colourless blood-corpuscles, and amphioxus none whatever.—The blood-corpuscles of the *invertebrata* resemble the colourless cells of the blood of the higher animals, and are almost always uncoloured.

Fig. 213.

1. Blood-cells of the frog. *a.* seen from the surface; *b.* from the side; *c.* decolourised by water. 2. Blood-cells of the pigeon. *a.* seen from the surface; *b.* from the side.

As *extraordinary* constituents of the blood we still have to mention here the following: 1, *cells, inclosing blood-corpuscles*, observed by *Ecker* and myself in the blood of the spleen and hepatic vessels, and also elsewhere in the blood (see my *Micr. Anat.* ii., 2, p. 269, *et seq.*); 2, *pigment-cells* and *colourless granular cells*, observed by myself, *Ecker*, *Meckel*, *Virchow*, and *Funke*, especially in intermittent fevers, and in affections of the spleen; 3, *peculiar concentric bodies*, three or four times the size of the colourless blood-corpuscles, and similar to those of the thymus (see HENLE, *Zeitschrift f. rat. Path.*, bd. vii., p. 44), found by *Hassall* in fibrinous coagula of the heart;

4, caudate cells, pale or with pigment (VIRCHOW, *Arch.* ii.); 5, pale, finely granular, roundish heaps, found by *Funke* in the blood of the splenic vein, and by myself in the blood of the spleen and liver in sucking animals. In the latter case they are little masses 0·01‴ to 0·02‴ in size, with an ill-defined outline, and with nuclei which swell up in water to 0·0005‴ or 0·0008‴. These dissolve rapidly in alkalies, and after a while in acetic acid; but they are not attacked by ether and alcohol and probably consist, therefore, of particles of easily soluble albumen. — We have still to mention here the elementary forms arising external to the body, or on stagnation of the circulation, the fibrinous *coagula* and red *crystals*. The former, as they appear in blood-coagula, mostly have the form of fine fibrils extremely densely matted together in an irregular manner, with here and there some thicker and straighter fibres, which measure uniformly 0·001‴ to 0·002‴ in breadth. These fibrinous elements are also said to occur in the form of plates resembling epidermis-scales (fibrine flakes, *Nasse*).—The red crystals which form from the blood, have of late years received increasing attention. They are of two kinds, the one occurring in normal fresh blood, spontaneously or on mere desiccation; the other kind being met with in old effusions of blood, in decomposed specimens, or in blood subjected to certain chemical agencies. Crystals ranged under the latter head may be divided into three sorts: 1, the so-called *hæmatoidin* crystals, described by *Virchow* in old extravasations, which have the form of rhombic plates, characterised by their insolubility in water, alcohol, ether, or acetic acid, and also by their giving with strong sulphuric acid, a play of colours similar to that produced by nitric acid on the colouring matter of the bile; 2, certain crystals observed by *Leydig* (*Zeitschr. f. wiss. Zool.*, 1, p. 266), and *Berlin*, in specimens of decomposed blood from the stomach of the clepsine, and of a kind of mite called *amblyomma exornatum*; 3, red, brown, or even black crystals, produced by *Teichmann* in blood, by the agency of acetic acid; considered by their observer to be pure hæmatin, and named accordingly, *hæmin-crystals* (*Zeitschr. f. rat. Med.*, Bd. iii., 1853, p. 375; and viii. p. 141). The interest of these last crystals has recently been greatly enhanced, from their having been used by *Brücke* in the diagnosis of blood-spots. A blood-stain is treated with distilled water, and the solution, with a little common salt, is evaporated *in vacuo* over sulphuric acid, then wetted with glacial acetic acid and evaporated on the water-bath. A few drops of distilled water being added to the product, *Teichmann's* crystals may be examined.—The other class of red crystals, those which are found in normal blood, perfectly fresh, were described by myself in the year 1849 (TODD'S *Cyclop. of Anat.*, June, 1849, Art. *Spleen*, p. 792; *Zeitschr. f. w. Zool.* i., p. 266; and *Micr. Anat.* ii., p. 280). I found them in the blood of the dog, of fishes, and of a python; sometimes within the red blood-corpuscles, sometimes free in the blood, especially of the spleen and liver. From their occurrence in the

Fig. 214.

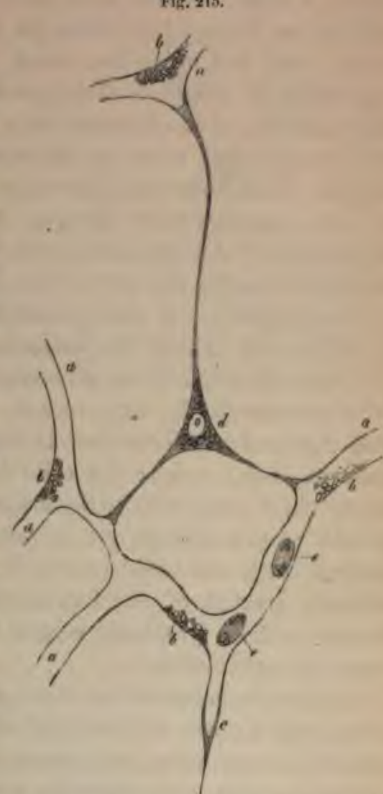
Crystals obtained from fresh blood. 1. prismatic crystals from man; 2. tetrahedra from the porpoise; 3. six-sided plate from the squirrel. After *Funke*.

former situation, I thought they were formed during life, and I conjectured that they were chemically related to hæmatin and hæmatoidin, though their solubility in acetic and nitric acids and in caustic alkalies, showed they were not identical with the latter. Two years later, without knowing my investigations, *Funke* discovered these crystals in the splenic blood of the horse and dog, of man and of fishes; and thereupon it was found by *Kunde* (*Zeitschr. f. rat. Med.* ii., p. 271, 1852), that they are invariably present in the blood of that organ; and their interesting tetrahedral and hexagonal forms were at the same time indicated by this observer. It is now demonstrated by the careful researches of *Funke*, that these crystals are only formed outside the body (see FUNKE'S Essay, *De Sanguine venæ Lienalis*, Lips., 1851, and his papers in HENLE'S *Zeitschr. N. Folge*, Bd. i., p. 172, and his more recent observations on fishes in the same work, ii., p. 199). *Funke* gives as his opinion, that these crystals are composed of the globuline of the blood-corpuscles in combination with hæmatin; and this view receives confirmation from the complete researches of *Lehmann*, to whom we owe many beautiful experiments on these crystals (*Phys. Chem.*, i., p. 365, and ii., p. 151, 1853).—For further particulars, I would refer to the writings above quoted, and to my *Micr. Anat.* ii., 2, pp. 585, *et. seq.*, and here I will only add a few brief remarks. The crystals of hæmato-crystallin (*Lehmann*) or 'globuline-crystals' as I have named them, are most readily formed by allowing a drop of blood covered with an object-glass to become somewhat dried up, or by the slow evaporation of the sediment of beaten blood, which has been diluted with water. They are red or colourless crystals, which assume the form of needles, columns and plates, probably belonging to the rhombic system, but they also occur as tetrahedra, octohedra (guinea-pig, rat, mouse), or as hexagonal plates (squirrel): they are characterised by their slight stability, disappearing when exposed to the air, and by being readily soluble in water, acetic acid, alkalies, and nitric acid. The crystals are rendered insoluble by alcohol; yet, on the addition of acetic acid, they swell up to three or four times their original size, returning to their former volume when the acid is washed out (*Reichert's* crystals).

§ 222. *Physiological Remarks.*—In the *development* of the blood-vessels, we have first to consider the process as it occurs in the arteries and veins. There it takes place according to two different types. The first type is witnessed in all the primitive embryonic vessels, and probably, also, in many later ones, which develop during the growth of organs; it is also seen in the vessels of the heart. It consists in the formation of *solid cellular cords*, of greater or less thickness, which are afterwards formed into cavities by the diffluence of their interior portions, and the metamorphosis of their central cells into blood-globules; and these cavities, at first separated, soon coalesce and form a perfect system of canals. The rudimentary heart of the embryo is formed in the same manner, and, even while in this cellular condition, may be seen to perform contractions. When the vessels and the heart have continued for some time in this condition of cell-tubes, the cells of their walls (the innermost cells excepted) commence to elongate into fibres, and to represent the different fibrous tissues and coats. At the same time, the vessels become thicker; at first, perhaps, from an increase in number of their cells, by a deposition of new cells from the surrounding blastema rather than by an independent multiplication of them; subsequently, however, the increase in the thickness of the vessels is effected chiefly, if not wholly, by the growth of their elements in length and in thickness.—In the other type, which has hitherto been little studied, the larger vessels are developed by metamorphoses of capillaries; cells being deposited externally upon them, and being gradually transformed into the different fibrous tissues of the arteries and veins. According to my observations, this mode of development is much more widely distributed than the former; and, at any rate, it is the manner in which all the larger vessels are formed in the organs, after the latter have once left their rudimentary condition. In the fifth month of intra-uterine life, the coats and tissues of all the larger and middle-sized vessels may be traced, and it is impossible to perceive a trace of formative cells; but, on the other hand, the tissues appear far from being fully developed, the muscular fibres are short and delicate, and instead of thick, elastic, fibrous networks, there are only fibrils of the finer kinds; while in place of the elastic membranes themselves, we find only layers of fusiform cells, more or less coalesced. In many vessels at this period, only the longitudinal fibrous coat can yet be demonstrated, appearing as a homogeneous, elastic membrane, close beneath the epithelium; yet even this is absent in the smaller vessels, and in its stead is found a layer of elongated cells, from which it, in its turn, appears to be formed. It is believed that similar cells are occasionally seen in the adult also, in those vessels where even the elastic inner coat is absent.—The muscular fibres of the heart arise as in other situations from coalescing cells, only that here the cells become stellate, and unite with processes from neighbouring cells to form the anastomoses which characterise the later development of these striated fibres.

The mode of formation of the capillaries is entirely different from that of the larger vessels, consisting, as *Schwann* and myself have shown, in a coalescence of simple cells. On the first origin of these vessels, the larger kind of capillaries are formed before the others, by the deposition, in linear series, of roundish, angular cells, which coalesce with each other by the absorption of the partitions and the contents; while the nuclei remain lying on the cell-membrane, which has now become the coat of the capillary vessel. In the next place, delicate, pointed processes bud forth from the walls of these vessels, and these quickly become elongated, and meet with similar pointed processes, derived from stellate cells scattered in the surrounding tissue. These processes coalesce at their point of meeting, and, at the same time, other prolongations of the cells unite with each other, so that a network is produced, consisting of the stellate cells with the already formed capillary tube or tubes. This network, however, is never extensive, for the processes which issue from the perfect capillaries already formed, as well as from the cells which join them, are always quickly transformed into capillaries by the thickening and hollowing out of the prolongations. In this manner vessels are produced which are at first extremely fine, and only receive blood-plasma (genuine *vasa plasmatica s. serosa*); but they soon become wider, till at last even the blood-globules pass through, and the capillaries are then fully formed. During this enlargement of the processes of the stellate formative cells, the bodies of the cells do not enlarge correspondingly, but simply appear as nodular points in the vessels; thus it happens that every trace of the primitive network of cells gradually disappears, and the position of the cell-bodies can afterwards only be made out from the situation of the persisting nuclei. When these finer tubes have once been formed from the primitive larger capillaries, the enlargement of the vascular system proceeds further and further from these new vessels, other stellate cells becoming widened to form capillaries, while, at the same time, new material

Fig. 215.



Capillaries from the tail of a tadpole. *a.* Fully-developed capillaries; *b.* cell-nuclei and remains of the contents of the primitive formative cell; *c.* cæcal processes of a vessel; *d.* stellate formative cell, connected by these processes with three similar processes of pervious capillaries; *e.* blood-globules, still containing some granules. Magnified 350 times.

for the vessels is being constantly supplied by the formation of new cells. New connections, also, are frequently formed between the already pervious capillaries, partly from the direct coalescence of processes, partly from connections with interjacent formative cells; so that by this means, of course, the primitive network becomes denser.—This mode of formation holds good, without exception, as far as I have seen, for all creatures in which capillaries occur; and the objection raised in various quarters against the exposition of *Schwann* and myself, have chiefly resulted from the circumstance, that observers have regarded every network uniting the arteries and veins in the embryo as consisting of capillary vessels. This, however, is by no means the case; and, accordingly, it is no contradiction whatever to our views, that the so-called capillaries of the germinal area, which are no capillaries at all, should arise after the type of the larger vessels.

The capillaries of the lymphatic system, which can be readily traced in the tail of the batrachian larva (fig. 205), have exactly the same development in all essential points as those of the system of blood-vessels (fig. 215), except that here anastomoses are rare, and the mode of formation is more limited to the deposition of cells in linear series; the cells being either fusiform, or having three chief processes. Observations are wanting on the larger trunks of this system, yet it cannot be doubted that they agree entirely with the blood-vessels in their development. *Engel* has recently treated of the lymphatic glands (l. c.), and stated that they arise from lymphatic vessels which give out buds, and become variously convoluted.

The development of the blood-corpuscles in the embryo is pretty accurately known in its chief stages. The primitive blood-corpuscles in mammalia, and the vertebrata in general, are nucleated, colourless cells, with granular contents, which are perfectly identical with the formative cells seen in all parts of the young embryo. The first corpuscles are formed in the rudimentary heart and great vessels (in some places very early; in others, somewhat later) by separation from each other of the cells in the centre of these organs, and this separation results from the formation of fluid, the primitive blood-plasma, between them. From these colourless cells arise the first coloured blood-corpuscles; they lose their granules, and become filled with hæmatine; but retain their nucleus.

These coloured, nucleated, primitive blood-cells are spherical, more intensely coloured, and larger than the blood-corpuscles of the adult, but in all other respects, are similar to them. In a sheep embryo of 3½ lines long, the most of them measured 0·005‴ to 0·0065‴, but some only 0·0025‴ to 0·0035‴; in a human embryo, 4 lines long, they measured, according to *Paget*, 0·004‴ to 0·007‴. At first, these red, nucleated corpuscles, along with their colourless formative cells, constitute the only elements of the blood. But many of them soon commence to multiply by partition, growing first into an elliptical shape, some of them being even flattened, and then being extremely like the blood-corpuscles of amphibia. At this time the cells are 0·009‴ in length, and 0·004‴ to 0·006‴ in breadth; they produce two, or more rarely, three or four roundish nuclei, and then divide into as many new cells, through one or more constrictions.

Fig. 216.

Blood-corpuscles of a sheep embryo, 3½ lines long. *a*. Double and triple nucleated, large, coloured, blood-globules, in different stages of division; *b*. large, round, coloured blood-cells, one with its nucleus dividing; *c*. a smaller one. Magnified 300 times.

As soon as the liver begins to grow, this multiplication of the blood-cells in the entire mass of blood ceases, and soon, also (in sheep embryoes of 11 lines), we lose all trace of their development from the colourless, formative cells; on the other hand, as *Reichert* inferred, and as I have directly demonstrated, a very active formation of blood-cells appears in the liver, the reason of which may be found in the circumstance, that at this period all the blood of the umbilical vein, by which the embryo is supplied with new plastic materials, first flows into the liver, instead of into the general circulation, as formerly. In the formation of cells which henceforth goes on in the hepatic vessels, the multiplication of the blood-corpuscles, by partition of themselves, retires more and more into the background. Instead of this process, colourless, nucleated cells are formed in the blood of the liver, measuring, on an average, 0·003‴ to 0·004‴ (0·0015‴ to 0·006‴ at the extremes), and these become transformed, for the most part in the liver, into coloured, nucleated blood-cells by the formation of colouring matter in the cell-contents; this change takes place either immediately or after the colourless cells have multiplied in the way already described for the primitive red corpuscles. The place of origin of these colourless cells (the first proper white blood-corpuscles) is not yet ascertained; but I am of opinion that they are produced in great measure by the spleen, for it is certain that in the later half of fœtal life, this organ does transmit numerous colourless cells into the liver; and I have also observed the formation within the spleen of red nucleated cells, in the case of advanced embryoes, and during the first year of independent life. Moreover, it appears probable that at the earliest development of the liver, a portion of these colourless formative blood-cells have their origin in the process of formation of the vessels of this organ. The considerable size and the vascularity of the embryonic liver completely harmonises with this view of the new formation of blood-corpuscles in that organ, and this process probably continues in the liver and spleen throughout the whole period of embryonic life; at least, I have found it in quite advanced embryoes of mammalia, and also in newly-born infants: it becomes, however, of less and less importance, perhaps in connection with the appearance and further development of the ductus venosus (which, according to *Rathke*, is a secondary formation), because, in this way, a considerable part of the blood of the umbilical vein arrives directly in the circulation, and is withdrawn from the liver.

The further development of the nucleated, spherical blood-cells of the embryo, in whatever manner formed, is effected by their gradually becoming more and more flattened (either directly or after they have multiplied in the manner stated above), and even by their receiving slight excavations; their nuclei, meanwhile, become decidedly smaller, and, on the addition of acetic acid, exhibit a great tendency to break up. They ultimately disappear completely, and the blood-cells become *non-nucleated,* like those of the adult, and soon, also, become like them in form, instead of remaining, as at first, of a somewhat irregular shape. As for the period at which these non-nucleated, coloured cells make their appearance, it is to be remarked, that I did not observe them at all in the embryo of the sheep, 3½ lines long, nor were they seen by *Paget* in a human embryo of the fourth week, which measured 4 lines in length. In embryoes of the sheep, 9 lines long, they were still extremely scanty; but in those which had attained a length of 13 lines, they constituted the great majority of the blood-cells. In a human embryo at the third month, these coloured corpuscles numbered about one-fourth of the whole in the blood of the liver; while in the blood of other parts, they constituted from one-sixth to one-eighth of the whole. In still older embryoes the non-nucleated cells greatly preponderate, so that in sheep-embryoes of 5 to 13 inches in length, the nucleated coloured cells in the hepatic blood constitute only one-fourth or two-fifths of the blood-cells; and in still larger embryoes, in the general mass of the blood, they are not more numerous than the lymph-globules in the blood of the adult. In the human embryo, it has not yet been ascertained at what period the nucleated, coloured cells become more scanty and disappear; but *Paget* has observed them in considerable numbers, in one case in an embryo of five months.—The blood of the more advanced embryo of mammalia contains large numbers of colourless cells besides the red corpuscles, and these are often equal in number to the coloured cells, and are found not only in the liver, but in the blood of other organs also. The chief part of these colourless cells is undoubtedly derived from the spleen and the liver; in the sheep's embryo, thirteen inches long, one-third of the total blood-cells of the liver are found to be of the colourless sort, with a few of the nucleated red corpuscles; in the later periods of embryonic life, many of these colourless cells may also come from the lymph. It is undetermined whether these later cells also become transformed into coloured corpuscles, and all that we can affirm concerning them is, that the stages of transition, which are so frequently met with in the blood of the liver and spleen (both in the white and in the nucleated red corpuscles), are entirely absent in the blood of the remainder of the body.

The origin of the blood-globules after birth and in the adult still remains one of the most obscure portions of their history, in spite of the numerous endeavours which have been specially directed to this point. The hypothesis which appears to me deserving of the most confidence is that which considers the red blood-cells to arise from the smaller chyle-corpuscles, which lose their nuclei and become flattened, while hæmatine is produced in their interior. These cells are not far from the same size as the blood-globules, or are even somewhat smaller; their membrane exhibits the same structure, they are flattened, and are not unfrequently coloured faintly yellow; hence they may pass into coloured cells without any considerable alteration, only such as we see in the colourless blood-cells of the embryo. No one has yet observed where and how the transformation takes place; and although I have devoted much trouble and care to this subject, I have never seen a nucleated, coloured blood-cell in the adult. The only observation bearing on this point which I have to record is, that in the pulmonary veins, and occasionally, also, in other blood, the smaller lymph-corpuscles have frequently appeared with a really pretty distinct colour, much more than in the thoracic duct; and thus it has happened that, as they lay on their sides, they were scarcely to be distinguished from true red blood-corpuscles, except by their slightly granular appearance. In this situation, too, the pale blood-cells showed somewhat smaller nuclei than elsewhere; but even this point is not conclusive. We may, however, adduce, as very important analogies in favour of this hypothesis, 1. that in all the lower vertebrata, even in the adult animals, the origin of the nucleated blood-cells from the lymph-corpuscles may be very distinctly observed; this is seen most plainly in the amphibia: and 2. that even in the human embryo, and in the spleen of the newborn child, the formation of the coloured blood-globules from colourless cells very similar to the lymph-corpuscles, has been demonstrated most definitely. When, moreover, it is considered, that nothing is known of an independent multiplication, or any other mode of origin of the blood-cells, I feel justified in expressing my opinion, that the red blood-cells take their origin from the lymph-corpuscles; and I would further venture to suggest, that the reason why the transition has never been observed is, that it takes place too quickly to be at all followed by the methods of observation which we can employ.

Although, in the foregoing, I have expressed myself in favour of the formation of the red blood-cells from the elements of the lymph and of the chyle, I do not by any means intend to assert that *all* the elements of these juices are transformed into blood-cells at all periods of post-embryonic life. The microscopical examination of the blood shows, indeed, that a certain number of large pale cells (with several nuclei, or with one nucleus which breaks up on the addition of acetic acid) are invariably present in fully-formed blood; and it appears impossible to suppose that these ever become red blood-corpuscles, although they certainly come from the chyle, or else are metamorphosed elements of it (*Virchow* and myself). If this be established, the question arises, whether the change of the blood-cells, their formation, and their decay, may not follow much more slowly than is usually assumed, and whether the pale corpuscles may not be much more stable elementary parts than has been hitherto supposed. I cannot give any definite explanation on this point, and will only remark, that in any case, as long as the body grows and the volume of the blood increases, an energetic formation of blood-cells must certainly be going on; on the other hand, it is wholly undetermined whether the blood-cells at this period of life undergo any process of solution, and on this account, therefore, we are unable to estimate what proportion of the elements of the chyle undergoes transformation into blood-corpuscles. In the adult, only this much, perhaps, is quite certain, that when, from any cause, the individual becomes poorer in blood, it may be replaced in a short time, together with its red blood-cells; but it is quite undetermined whether, under ordinary conditions, an energetic solution and re-formation of blood-cells takes place. Since a formation of blood-globules cannot be definitely observed, we can only hope to bring this question to a decision by seeking for proofs of their solution; but the observations which we possess on this point are not of a nature to warrant the inference, that a change of the elements of the blood is constantly taking place at short intervals; for though an enormous number of decomposing blood-globules may be found in the spleen of many animals, still the frequent and regular return of a process of solution of the blood-corpuscles in this organ has not yet been demonstrated. Taking together all the facts known to us, I believe, then, that the question, when and in what measure the blood-globules of the adult perish and form anew, cannot possibly be determined definitely at present; yet I am inclined to the opinion, that the elements of the blood are, throughout, less transitory structures than is usually believed.

The *investigation of the heart* is easy, as regards the muscular fibres themselves, and their anastomoses may be detected with facility in any carefully made preparation; on the other hand, there are great difficulties in tracing the course of the fibres in this organ. Hearts which have been macerated in weak alcohol are best adapted for this purpose, and it has long been recommended to employ hearts that have been boiled, either when fresh or after being salted for some weeks. In place of this method, *Purkinje* and *Palicki* recommend the heart to be boiled in a solution of common salt, or still better, of sulphide of calcium; while *Ludwig* prefers to remove the pericardium, and then to lay the heart in water, repeating the soaking along with a gentle pressure every time that he removes a layer of the muscular fibres.—For the *blood-vessels*, previous dissection of them into lamellæ with the knife and forceps, however carefully performed, does not suffice; but their investigation must also be conducted by means of transverse and longitudinal sections of the entire wall of the vessels. Portions of the vessels should be spread out and dried on paper, and then a fine section, even of very thin vessels, may be obtained. Sections thus obtained should be softened in water before examination; they should be treated with acetic acid or with nitric acid of 20 per cent. (*Weyrich*), if we desire to study the muscular fibres; other preparations should be treated with caustic soda, and in these ways, the elastic tissue of the vessels comes out very beautifully. For the rapid demonstration of the epithelium, of the elastic inner coat, and of the muscular coat, by themselves apart from their connections, the large vessels at the base of the brain have shown themselves to me to be best adapted. The elastic membranes of the tunica media can be readily isolated after maceration in acetic acid. The muscular fibres of this coat are always seen on teasing it out, or come into view readily on the addition of nitric acid.—For the study of the capillaries the brain and the retina in man, as well as tadpoles and embryonic structures, are especially to be recommended; for the development of the capillaries, tadpoles, the allantois of embryoes, and the vascular capsule of the lens, should be examined.—The blood is to be examined, whenever possible, in the serum itself, then with the different re-agents mentioned above; and its extreme tendency to undergo alteration is always to be borne in mind.—The lymphatic glands are best injected with carmine and size, or with sealing-wax and turpentine dissolved in alcohol; and I recommend, in addition, sections of preparations which have been hardened in alcohol.

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OF THE HIGHER ORGANS OF SENSE.

I. OF THE ORGAN OF VISION.

§ 223. The organ of vision consists of the *eye-ball*, or the proper sensory apparatus, together with certain *accessory parts*, which are present partly for its protection, partly for its movement; these are, the *eye-lids*, the *muscles* of the eye, and the *lachrymal organs*. The eye-ball itself is a very complex organ, in which almost all the tissues of the body are represented; and it is essentially composed of two internal refracting media, the vitreous body and the lens, together with three coats or tunics: the outermost *fibrous*, comprising the sclerotica and cornea; the next *vascular*, the choroid with the iris; and the third is the *nervous* coat.

A. OF THE EYE-BALL.

§ 224. *Fibrous Tunic of the Eye.*—The external envelope of the eye-ball is formed by a dense fibrous tunic, which, to outward appearance, is subdivided into a smaller, anterior section, the *cornea*, which is transparent; and into a larger, posterior, opaque part, the *sclerotic*; although the whole is to be regarded as a single connected tunic, as is proved by its development as well as by its intimate structure.

The *sclerotic* coat, also called the *tunica albuginea*, is a white, fibrous membrane, very dense and firm, which is thickest at the posterior circumference of the eye, where it is directly connected with the sheath of the optic nerve, and becomes gradually thinner as it advances forwards, becoming, however, again stronger at its anterior part, where it receives the insertion of the straight muscles of the eye; hence it is continued uninterruptedly into the *cornea*. The sclerotic yields ordinary gelatine on boiling, and consists of true connective tissue, whose fibrils come out very distinctly, both when teased out, and also when transverse sections are treated with acetic acid. The bundles of this tissue are straighter, but otherwise are intimately connected together as in tendons, and they are united to form largish flat bands of various thickness, which run alternately in a longitudinal and in a transverse direction in the entire thickness of the coat, so that a lamellated structure is exhibited on perpendicular sections. True independent laminæ, however, are nowhere present, the different longitudinal layers, as well as the transverse ones, being variously united with each other. It is only on the two surfaces of the sclerotic, but especially on the inner, that the longitudinal fibres collect to form somewhat thicker plates, and thus receive greater independence.

Through the midst of the connective tissue of the sclerotic, there run a great number of fine elastic elements, which have the same form as in tendons and ligaments (see § 80), viz., a network of fibres of various degrees of fineness, in which the places where the primitive formative cells were situated are indicated by thickenings with rudiments of nuclei, so that the whole often bears a close resemblance to anastomosing, fusiform and stellate cells. During life, the elementary fibres of this network appear sometimes to possess cavities with fluid contents, at least, in dried sections of the sclerotic, air is seen in the bodies of all the cells, giving rise to the appearance known as the 'cretaceous corpuscles' of *Huschke*. *Virchow's* view, according to which these cavities are a kind of nutrient canals, may, accordingly, be considered as fully warranted, especially as the vessels of the sclerotic are always very scanty. These *vessels* arise chiefly from the ciliary arteries and from those of the muscles of the eye-ball, and, as *Brücke* and myself have found, they form a tolerably wide-meshed network of capillaries of the last order. I have not yet seen any nerves in the sclerotic, as described by some; the appearance of nerves in it probably results from branches running on its inner side to the ciliary ligament.

The cornea is perfectly transparent, denser, and more difficult to tear than the sclerotic, and is composed of three special layers:

1. of the *conjunctival* membrane (*conjunctiva corneæ*); 2. of the *proper cornea*; and 3. of the membrane of *Descemet*: the first and the last of these layers are formed by an epithelium and a subjacent structureless membrane; the middle one of a fibrous tissue of a peculiar kind.

The *proper cornea*, or the fibrous layer of it, constitutes by far the thickest part of the whole coat, and consists of a fibrous substance nearly allied to connective tissue, but yielding, according to *J. Müller*, chondrin instead of gelatin on boiling. This chondrin, however, is stated by *His* to differ from the ordinary kind, in the circumstance that most of its precipitates are soluble in an excess of the precipitating re-agent. Its elements are pale bundles, 0·002‴ to 0·004‴ in diameter, on which, at least when teased out, fine fibrils are more or less distinctly visible. These, again, are united to form flat bundles, of 0·04‴ to 0·12‴ in breadth (*His*), which keep their surfaces always parallel to the surfaces of the cornea, and are connected with each other, both in the direction of the surface and in that of the thickness, so that they represent a large meshwork extending through the entire tunic. There are, however, no visible spaces in the membrane, seeing that, on the one hand, the elements of one fibrous fasciculus press closely into the intervals of another, and that, on the other hand, all the fibrous bundles themselves lie very compactly one upon another, as in a compressed sponge, for example. The structure of the cornea may be most correctly and easily understood, if we proceed from the sclerotic, of which the corneal tissue is only a modification. We have seen that in the sclerotica, bundles of connective tissue, arranged in longitudinal and transverse networks, constitute the whole tunic; and the same is the structure of the cornea, only more complicated, the bundles here running in the most diverse directions.—If we regard the structure of the cornea as a whole, we may ascribe to the tunic a lamellated arrangement, although we cannot agree with many authors, in stating that it consists of complete lamellæ. This arrangement results from all its bundles being flat, and lying with their surfaces parallel to the surface of the cornea, so that this structure cannot, without extreme difficulty, be torn and penetrated in the direction of its thickness.—The correspondence of the elements of the cornea with connective tissue is also proved by the following considerations: 1. that it is continued at its borders (chiefly by its radiating elements), directly and without interruption, into the similarly disposed fibres of the sclerotic, so that a natural separation of the two tunics cannot be regarded as existing in the slightest degree; and 2. that between the bundles and lamellæ of the cornea there lie an enormous number of anastomosing, fusiform and stellate, nucleated cells, the 'corpuscles of connective tissue,' or 'cornea-corpuscles' of *Virchow*, which were first noticed by *Toynbee* in 1841, and afterwards more distinctly by *Virchow*: cells of these characters are peculiar to undeveloped elastic tissue, and also occur in a more branched form in the sclerotic. It is probably beyond doubt, that the nutrient fluid, which continually saturates the cornea in large quantity, and which can be directly demonstrated by pressing the cornea, is chiefly conducted and distributed further into the interior by the cells in question; and this view appears to receive confirmation from the fact, that in diseases of the cornea these cells very frequently contain fat-drops, and in exceptional cases, according to *Donders*, even pigment in their interior. The *corneal tubes*, which have been injected by *Bowman* in the ox and in the human eye, are not to be confounded with cell-networks; and they are probably to be regarded as artificial enlargements of the small interspaces which normally occur between the elements of the cornea-tissue, and which, on microscopical examination, may occasionally be indistinctly recognised.

Fig. 217.

Perpendicular section of the cornea of the newly-born infant; magnified 350 times, and treated with acetic acid. The epithelium is left out. *A*. Anterior portion of the cornea. *a*. Anterior structureless lamella; *b*. dense layer of small round granules (probably small cells), with a small quantity of fibrous tissue; *c*. developed fibrous tissue, with anastomosing plasmatic cells. *B*. Posterior portion of the cornea. *c*. As above; *d*. structureless lamella of the membrane of *Descemet*.

The *conjunctiva* covering of the cornea chiefly consists of a soft, lamellated epithelium, 0·023‴ to 0·050‴ thick, whose lower layers of cells are elongated and disposed perpendicularly upon the cornea; while the middle ones possess rather a roundish form, and pass superiorly into a layer 0·008‴ to 0·01‴ thick, of soft, nucleated plates (0·01‴ to 0·014‴ in size), corresponding to the horny layer of the epidermis. This epithelium becomes dim very soon after death, as also on the addition of water and acetic acid. Beneath it there exists a *structureless* lamella, first mentioned by *Bowman*, and named by him the 'anterior elastic lamella;' this measures

0·003‴ to 0·004‴ in thickness, and is especially distinct upon perpendicular sections, and when horizontal sections are folded together after the addition of alkalies. This lamella, however, is far from being so sharply marked off from the proper cornea as *Descemet's* membrane, nor does it appear to have the same signification as that membrane, being, perhaps, nothing else than the remains of the vascular lamina which previously existed in the corneal conjunctiva. — Curved fibres, like rigid bundles of connective tissue or elastic fibres, are occasionally seen to pass off from this conjunctival membrane for some distance into the cornea, where they are lost.

The membrane of *Descemet*, or *Demours*, called also *membrana humoris aquei*, consists of an elastic membrane, rather loosely attached to the tissue of the cornea, and of an epithelium upon the inner surface thereof. The former elastic layer, which is the proper membrane of *Descemet*, is clear like glass, brilliant, perfectly structureless, and can be readily torn; it is, however, tolerably firm, and so elastic, that when it is separated from the cornea by the knife and forceps, or by boiling in water, or by maceration in alkalies, it invariably curls up strongly, with a direction forwards. By this treatment, as by re-agents in general, the membrane is not deprived of its transparency; it appears to be identical in its chemical characters with the other homogeneous membranes. The thickness of *Descemet's* membrane amounts to 0·006‴ to 0·008‴, and towards the borders of the cornea, it passes into a peculiar system of fibres, which were first observed by *Reichert*, and described more at length by *Bowman*. This system of fibres commences at a small distance from the border of the cornea at the *anterior* surface of *Descemet's* membrane, and first forms an elongated network of fine fibrillæ, like fine elastic fibrils; these then become gradually denser, till, at the border of the cornea itself, *Descemet's* membrane has broken up in its entire thickness into a network of thick fibres and trabeculæ, which divides into three portions. The one part turns round in the whole circumference of the anterior chamber of the eye in the form of numerous processes, which pass freely through this chamber upon the anterior border of the iris; these constitute the *lig. iridis pectinatum*, and coalesce with the anterior parts of this structure. Another portion passes into the ciliary ligament, or rather, into the musculus ciliaris; and the remainder of the network prolonged from *Descemet's* membrane is lost in the inner wall of the canal of *Schlemm* (see below, under the account of the *uvea*). *Descemet's* membrane, accordingly, does not, therefore, terminate with a sharp border, as is usually stated; but, as *Reichert* first pointed out, appears to pass altogether into a peculiar fibrous tissue. Opinions are divided concerning the nature of these fibres; for while *Reichert* classifies them with connective tissue, and *Brücke* regards them as peculiar, *Luschka* declares that they belong to the so-called serous fibres (*i.e.*, fibres of elastic tissue). *Bowman*, again (*Lectures*, p. 21), and *Henle* (*Jahresb.*, 1852, p. 20), consider these fibres to be partly of the nature of elastic tissue, partly of connective tissue, while I myself view them as a form intermediate between these two tissues. The truth is, that these fibres, where they commence on the membrane of *Descemet*, and in their continuations to the wall of the canal of *Schlemm*, and to the ciliary muscles, seem to belong to the category of elastic fibres from their dark contours, their moderate thickness, and homogeneous appearance; while the parts which are continued upon the iris present a great resemblance, morphologically, to connective tissue, viz., in their breadth (0·004‴ to 0·012‴), their paleness, and in having a well pronounced striated appearance. This resemblance is so striking, that I formerly (*Zeitsch. f. wiss. Zool.*, i. p. 54), considered this portion of the fibres as being a reticulate connective tissue. I must now, however, maintain, as in the first edition of the work (notwithstanding the assertion of *Henle*, that the *lig. iridis pectinatum* is really connective tissue), that these fibres in man differ widely from connective tissue in their rigidity, in their reactions towards alkalies and acids, and in their insolubility even on long boiling in water. They are, indeed, closely allied to the elements of the zonule of *Zinn*, which *Henle* himself does not regard as connective tissue.—Nevertheless, I must observe, that in *animals* some of these fibres do possess other characters than in man. Thus, in the rabbit, I find, in their place, thick bundles of *connective* tissue with plasmatic cells, or immature elastic elements, which are fixed in a pointed manner into *Descemet's* membrane, and thence expand and are lost in the outer part of the iris; in birds, on the other hand, the fibres are distinctly those of *elastic* tissue.

The epithelium of *Demours's* membrane, which is frequently found destroyed by decomposition in the human subject, is a simple layer, 0·002‴ to 0·003‴ thick, of beautiful polygonal cells, 0·006‴ to 0·01‴ in size, with extremely fine and pale granular contents, and round nuclei, 0·003‴ to 0·005‴ in diameter. Towards the border of the cornea the cells become smaller, and the epithelium then terminates as a connected layer. On the other hand, isolated streaks of epithelial cells, mostly elongated, or even fusiform, are continued over the fibrous networks of the *lig. pectinatum* (enclosing its elements) to the border of the iris, where a complete epithelial layer again appears.

In the adult, the *cornea* is almost entirely destitute of *vessels*; while, on the other hand, as *J. Müller* and *Henle* (*De Membr. Pupill.*, p. 44) first observed, a rich vascular network occurs in the embryonic *conjunctiva corneæ* in man and in the sheep, but this does not appear to extend as far as the middle of the cornea. Towards the end of fœtal life, this network becomes indistinct in man more than in animals, so that in the human cornea blood-vessels are met with only at the border, in a ring of half a line, or at most, of one line in breadth. They are mostly fine and finest capillaries, 0·002‴ to 0·004‴ in diameter, which form one or more series of curves, and thus terminate; they likewise lie in the substance of the conjunctiva, which here extends as a demonstrable lamina for some distance upon the cornea, and then terminates in its anterior structureless layer. These *superficial*, or *conjunctival* vessels also occur in animals, but are much more beautiful, and extend further inwards, often to one-half the radius of the cornea, or even further. In addition to these, deeper capillaries, derived from the sclerotic, occur in the cornea itself, and these mostly accompany the nervous trunks; in these they either form one or more very elongated loops, or they extend a little beyond them: they invariably terminate by the loops, whose finest vessels, as in the superficial capillaries, measure scarcely more than 0·002‴ in diameter. I have likewise seen these proper corneal vessels in man, but not constantly, and never so well developed as in the lower animals.

Nothing certain is known of the *lymphatic vessels* of the cornea (compare, also, ARNOLD, *Anat.*, ii. p. 988); but I have recently observed some peculiar vessels in the cornea of a young cat, which I can scarcely consider as being anything else than lymphatic vessels. At the border of the cornea, along with very distinct capillary loops containing blood-corpuscles, there were found pale vessels of much greater width (0·01‴ to 0·02‴, or even 0·03‴ in diameter), which either extended singly into the cornea, as far as the blood-vessels, and then terminated with bulbous or pointed extremities, or else formed simple loops of two, three, or more together, from which loops other cæcal processes were frequently given off. Notwithstanding their width, these vessels possessed a delicate, structureless coat, with scattered nuclei, and they contained in their interior a clear juice, in which clear round cells, exactly like lymph-corpuscles, were to be seen; these were usually in small numbers, but occasionally were very numerous.

The nerves of the cornea, which were discovered by *Schlemm*, are derived from the *nervuli ciliares*, enter this coat at the anterior circumference of the sclerotic (in the rabbit, according to *Rahm*, at the posterior half of the globe), and then pass from it into the fibrous layer of the cornea. Here they are readily found at the border, forming, in man, twenty-four to thirty-six trunklets of various degrees of fineness, but scarcely ever exceeding 0·02‴ in diameter. These nerves are distinguished by their mode of distribution, which is effected by numerous dichotomous divisions and anastomoses, so that a wide nervous network is produced, extending through the whole cornea; they are, however, especially remarkable for the circumstance, that they contain fine, dark-bordered, primitive tubes (0·001‴ to 0·002‴), only at the margin of the cornea, within a zone half a line to one line in average breadth; while in their further course they possess only non-medullated fibres, completely *clear* and *transparent*, measuring 0·0003‴ to 0·001‴ at the most: thus, in *any* case, they do not impede the passage of the rays of light more than the other elements of the cornea, as is evident from the difficulty with which they are traced under the microscope. Bifurcations of the primitive tubules present themselves, though rarely, in the trunks of these nerves, but never in the plexus formed by them, the condition of which, however, can scarcely be fully investigated, on account of its paleness. This plexus lies in the proper cornea, but nearer to the anterior surface; and, since no trace of free terminations of nerve-fibres is to be seen, it would appear to consist solely of anastomosing twigs of the finest kind, so that, if not in the form of loops, still some connection of the nerve-tubes with one another may be assumed.

Fig. 218.

Nerves of the cornea of the rabbit in their coarser ramifications. The distance to which the dark-bordered tubes extend in the trunks is here expressed by the darker portions of the lines.

The blood-vessels of the *conjunctiva corneæ*, of healthy individuals, are very scanty, and those which are figured by *Römer* (AMMON's *Zeitschr.* v., 21, tab. i.

figs. 9, 11), and *Arnold* (*Icon. Org. Sens.* ii., fig. 6), I regard as exceptional cases; but, on the other hand, as is well known, these vessels become so developed in inflammations, that they cover the whole, or almost the whole, cornea. The proper vessels of the cornea likewise appear in such cases to extend further inwards. With regard to the vasa serosa corneæ, I would refer to my *Micr. Anat.* ii., 2, p. 624, *et seq.*—The cornea, although vascular only at the border, is still not unfavourably placed with reference to its nutrition. Wounds of the cornea readily heal; portions of the epithelium or even of the fibrous layer are restored after removal, and ulcers fill up from the bottom with new corneal substance. Depositions of fat in its tissue, especially in its cellular bodies, produce at the border (especially above, but also at the lower margin, or even round the entire circumference), a yellow zone, the so-called 'arcus senilis' (*gerontoxon*). In all pathological alterations of the cornea, as *His* has clearly shown, the cells of the cornea play a chief part, especially by their enlargement, and by the production within them of numerous nuclei or endogenous cells, a change on which all subsequent metamorphoses appear to follow (*His*, l. c., pp. 73—140).—On the membrane of *Descemet* peculiar warty excrescences are occasionally found, and to a slight degree this appearance is not uncommon even in healthy eyes (*H. Müller*).

§ 225. *Vascular Tunic* or *Uvea.*—The second tunic of the eyeball is an extremely vascular structure, containing a large amount of pigment, and may be divided into a larger posterior section, the *choroid*, and a smaller anterior portion, the *iris*.

The choroid coat extends forwards from the place of entrance of the optic nerve as far as the iris, with which it is continuous. In the former situation it presents a circular aperture, but is connected with the neurilemma of the optic nerve, and passes transversely through the nerve in the form of a delicate cribriform layer. The choroid is a fragile membrane $\frac{1}{18}'''$ to $\frac{1}{30}'''$ thick, but at the anterior border of the sclerotic it forms a thicker part, the *corpus ciliare.* Its outer surface is pretty intimately attached to the sclerotic, not only by the larger vessels and nerves, but also by other means, so that on exposing the choroid, a part of it, of greater or less extent, remains fixed on the sclerotic as a delicate brown tissue. This is the so-called *lamina fusca* of authors, but there is no sufficient reason for separating it from the choroid and describing it as a special coat; although it is true that separate pigment cells, such as occur in it, do often extend in among the connective tissue of the sclerotic. The inner surface of the choroid is smooth, and is connected with the retina very firmly at the *ora serrata,* but is only loosely adherent in the rest of its extent: on the other hand, in front of the *ora serrata*, on the ciliary processes particularly, it is very intimately united with the *pars ciliaris retinæ,* and with the hyaloid membrane (*zonula Zinnii*), so that it can never be completely detached from these spots.

The choroid consists essentially of two parts, of a thicker external vascular lamina, the *proper choroid*, and of an inner distinctly-coloured layer, the *black pigment of the eye*. The former, however, can be divided into three strata, of course not sharply separated from each other; they are, 1, an outer brown, soft lamella, which supports the ciliary nerves and long ciliary vessels, and contains anteriorly the *musculus ciliaris*; this is named the 'external pigment lamina' (*lam. fusca et supra-chorioidea* of authors); 2, the less-coloured *proper vascular layer*, with the larger arteries and veins; and, 3, a colourless delicate inner layer, containing an extremely rich capillary network, the *membrana choriocapillaris*, which, however, does not extend further forwards than the *ora serrata*. With regard to the tissue forming the proper choroid, a great portion is made up of vessels and nerves, and of the ciliary muscle; but beyond these there is found a peculiar tissue, which I classify with the elastic tissue. In the outer parts of the tunic, this basement tissue or *stroma* is formed by nucleated cells, of an irregular, fusiform, or stellate shape, and either quite pale, or containing some brown pigment. They measure 0·008‴ to 0·02‴ in length, and anastomose irregularly with each other by shorter and longer processes, which are mostly very delicate (measuring 0·0005‴ in breadth), but somewhat rigid and pale; by the large number of these anastomoses a loose membranous tissue results, which resembles in many respects the fine-fibred elastic membranes. In the inner layers of the choroid, and especially in the membrana choriocapillaris, these cellular networks, which I class with the networks of plasmatic cells, gradually pass into a homogeneous nucleated tissue, at first with a little pigment, but afterwards colourless, which is distinguished from connective tissue by its resistance to acids and alkalies. This tissue terminates close upon the black pigment, by a delicate membrane without structure, or finely fibrous, which may be exhibited separately, and is 0·0006‴ thick; this I have named the 'elastic lamella of the choroid.'

Fig. 219.

Cells from the stroma of the choroid. *a*, pigmentated cells; *b*, pigmentless fusiform ones; *c*, anastomoses of the former; magnified 350 times. Of man.

The *ligamentum ciliare* of anatomists, called also, *musculus* *ciliaris s. tensor chorioidea*, was recognised as being of a muscular nature, almost simultaneously by *Brücke* and *Bowman*: it is a tolerably thick lamina, of radiating, smooth muscular fasciculi, which pass from the most anterior border of the sclerotic to the *corpus ciliare*, and are lost in the anterior half of that body, at the spot corresponding to the situation of the ciliary processes internally. More accurately described, the ciliary muscle arises at that part of the sclerotic where it is furrowed for the formation of the venous sinus of *Schlemm*; indeed it is from a special dense, smooth tract, which forms the inner wall of the above-mentioned canal, and coalesces with the sclerotic, receiving a part of the fibrous networks prolonged from the membrane of *Demours*; the last-mentioned fibres coalesce perfectly with the similar elements of the special tract, which are, however, finer, anastomose more densely, and have a circular direction. The termination of the ciliary muscle is at the attached part of the ciliary processes, but not in these structures themselves. The muscular elements are somewhat shorter (0·02‴) and broader (0·003‴ to 0·004‴) than the ordinary fibre cells, and are finely granular and very delicate; they are, indeed, so perishable, that they cannot easily be isolated in the human subject. Very lately, *H. Müller* has discovered a circular muscular layer, quite anteriorly beneath the radiating fibres of the ciliary muscle; and this may be called the 'circular muscle of *Müller*.'

The *black pigment* completely lines the inner surface of the choroid membrane, as a connected purely cellular lamina, which consists, as far forwards as the ora serrata, of a single layer of beautiful cells, almost regularly hexagonal, 0·006‴ to 0·008‴ in diameter, and 0·004‴ in thickness, disposed in the manner of a mosaic; the large quantity of pigment in them allows the cell-nucleus to appear only as a clear spot in the interior; but this nucleus is seen on a lateral view to be situated in the outer half of the cells, where they are poorer in pigment granules. From the ora serrata onwards, the pigment-cells are arranged in two or more layers, becoming roundish, smaller, and quite filled with pigment, so that even the nuclei are scarcely visible. All the pigment-cells have very delicate walls, and are very readily ruptured by pressure; their pigment consists of extremely small,

Fig. 220.

Cells of the black pigment of man. *a*. seen from the surface, *b*. from the side; *c*. pigment granules.

flattened, oblong corpuscles, 0·0007‴ in length at the most, which, even within the cells, but more distinctly when they are free, present in a well marked manner, the phenomenon of molecular movement.—In the eyes of Albinos, and also, in a part at least, of the eye of animals, in the region of the *tapetum*, the pigment of the choroid is absent; the cells, however, which usually contain the pigment, are themselves present in both these cases, only they are perfectly pale.

The *Iris* differs from the choroid in containing a true connective tissue, whose delicate loose bundles constitute the chief mass of the stroma of the membrane; their course is in part radiating, in part circular, especially at the ciliary border, where they are variously interwoven with each other. Towards the surface of the iris, these loose bundles become converted into a more homogeneous layer; and in this there occurs, 1, a great number of cells, or plasmatic cells, frequently containing pigment, and mostly fusiform and stellate, more rarely roundish in shape; some of these anastomose in a reticulate manner; 2, a small number of pale, rigid fibres like elastic fibres, which extend as processes of the *ligamentum iridis pectinatum*, or of *Demours'* membrane, over a part of the anterior surface as far as to the *annulus minor*; 3, lastly, the smooth muscular fibres of the iris, which are exactly of the same nature as those of the choroid. These last form in man a very distinct sphincter muscle (*sphincter pupillæ*), in the form of a smooth ring, ¼‴ broad, situated exactly at the pupillary border, and somewhat nearer the posterior surface; in a blue iris, this can readily be recognised after the removal of the posterior pigment, either before or after the employment of acetic acid; and it can also be separated into its elements, 0·02‴ to 0·03‴ in length. Besides this larger muscular ring, I find in the region of the *annulus iridis minor*, another very narrow muscular ring, $\frac{1}{40}$‴ in breadth, and nearer to the anterior surface of the iris. I have not yet, like *Brücke*, traced the *dilator pupillæ* up to the *ligamentum pectinatum*, and to the border of the vitreous lamella of the

Fig. 221.

A part of the sphincter and dilator pupillæ of the white rabbit, treated with acetic acid; magnified 350 times. *a*. sphincter; *b*. fasciculi of the dilator; *c*. connective tissue with plasmatic cells, which has become transparent.

cornea; it rather appearing to me to commence in the substance of the iris at the ciliary border. It consists of numerous narrow fasciculi, which, far from forming a connected membrane, run inwards independently between the vessels, on the posterior surface of the iris more than on the anterior, and become inserted at the border of the sphincter.

The iris also differs from the choroid in possessing a layer of cells on its anterior and posterior surfaces. The latter, the so-called *uvea* of authors, or the black pigment of the iris, is a layer, 0·008‴ to 0·01‴ thick, of small cells densely filled with pigment, similar to those of the *corpus ciliare*, with which they are also uninterruptedly connected; this layer covers the whole posterior surface of the iris, and extends up to the border of the pupil. On folding the iris, the pigment layer appears limited on its free surface by a fine but well marked line, which has been described by several anatomists as a special membrane ('membrana pigmenti,' *Krause*; 'membrana limitans,' *Pacini*, *Brücke*, and *H. Müller*; M. Jacobi, *Arnold*); and in truth it may be partially raised from the pigment in old eyes, or after the addition of alkalies. Since, however, in such cases the pigment-lamina is always destitute of a sharp contour, and its granules are exposed and scattered, this membrane appears to me to be nothing but the outer walls of the pigment-cells united together, so that they may be separated apparently as a special membrane.—The layer of cells of the anterior surface of the iris, is a simple epithelium, of roundish and considerably flattened cells; and when the iris is folded, this layer does not appear as a continuous clear edge of uniform width, but is distinguished rather by the separate slight elevations on it. This layer may be still better recognised when the iris is viewed on its surface, after the removal of the posterior pigment, and also in scrapings of the anterior surface of the iris.—The colour of the iris, in blue eyes, is simply owing to the posterior pigment seen through it; while in yellowish-brown, brown and black eyes, the colour is due to a special pigment, which is very irregularly distributed through the iris, and then produces the peculiar appearances seen on the anterior surface. The pigment is situated, firstly, in the stroma itself, especially in its plasmatic cells; secondly, it appears to me to exist free between the fibres and vessels, and in the fibre-cells of the sphincter pupillæ; lastly, it is found in the anterior epithelial layer, where it consists of larger and smaller granules, heaps and stripes irregularly disposed, and having a yellow, orange, or brownish colour; the regular pigment granules of the proper pigment of the eye never being found here.

The *vessels* of the choroid and iris are extremely numerous, and present different conditions in the several parts. The *choroid* receives its blood from the *art. ciliares posteriores breves*, about twenty small vessels, which penetrate the sclerotic at the posterior circumference of the eye-ball, at a variable distance from the optic nerve, and then run forwards, dividing dichotomously in the middle or vascular layer of it, where they divide into three kinds of branches: 1, an external series, which attain a certain fineness by continued division, and then pass directly into the *venæ vorticosæ*; 2, an internal set, which pass into a capillary network immediately beneath the pigment of the so-called *membrana chorio-capillaris*; and, 3, an anterior series, which are continued into the *corpus ciliare* and the *iris*. The above-mentioned *capillary network* of the innermost layer of the choroid, which lies on the inner side of the *tapetum* in animals which possess this structure, may be readily demonstrated as a special membrane; indeed it may be partially shown even in man, in injected and fresh preparations, and it forms one of the densest and most beautiful plexuses ever met with, for the meshes between vessels of 0·004‴, themselves measure only 0·002‴ to 0·005‴, and the capillaries proceed in a stellate manner from the larger vessels. As already mentioned, this network reaches only as far as to the *ora serrata*, where it gives place to somewhat coarser vascular convolutions with vessels 0·004‴ in diameter, derived from the anterior branches of the *ciliares posticæ breves*; these form the *processus ciliares*, and are so thick, that besides the vessels and a more homogeneous envelope supporting the ciliary processes, no other tissue appears to be present in them. The blood is returned from these different regions (and from the ciliary muscle, which likewise receives some twigs from the above-mentioned arteries), chiefly by the *venæ vorticosæ*, which lie upon the arteries, two above and two below (sometimes

Fig. 222.

Vessels of the choroid and iris of a child, after *Arnold*, seen from within, and magnified 10 times. *a*, capillary network of the posterior section of the choroid, terminating at the *ora serrata*, *b*; *c*, arteries of the *corona ciliaris*, supplying the ciliary processes *d*, and partly proceeding to *e*, the iris; *f*, capillary network of the inner surface of the pupillary border of the iris.

five and six), and form beautiful stellate figures or whorls; it is returned also in the fundus of the eye-ball, by some small *venæ ciliares posticæ breves*, and all of these veins penetrate the sclerotic in the same manner as the arteries.

The *Iris* receives its blood, firstly, from the arteries of the choroid coat; and, secondly, from the *art. ciliares posticæ longæ*, and the *art. ciliares anticæ*. The anterior branches of the former vessels either pass directly into the iris, between the ciliary processes, or, after supplying the ciliary processes, form small trunklets at their border and anterior end, and these likewise proceed onwards to the iris. The long ciliary arteries, two in number, penetrate the sclerotic on the right and left, somewhat in front of the shorter vessels of the same name, and run in the outer pigmentary layer of the choroid, as far as to the *tensor chorioideæ*; here each divides into two branches, and unites with the *art. ciliares anticæ* (which, three to six in number, penetrate the sclerotic), producing in the muscle mentioned an irregular arterial ring, the *circulus art. iridis major*. From this circle very many radiated and tortuous branches are given off into the iris, and small vessels arise either from the circle, or from the vessels forming it, for the supply of the tensor muscle. Arrived at the iris, these vessels are distributed along with the above-mentioned arteries from the choroid coat, partly producing a small number of true capillaries, one layer more especially being situated on the posterior surface of the pupillary border beneath the pigment (*Arnold*); another part of the vessels running (with some dividing continually) as far as the border of the pupil, where they bend round and return into the veins by loops of delicate but not capillary vessels, which form a second *circulus arteriosus minor*, usually imperfect, in the region of the *annulus iridis minor*. The veins of the iris arise from the above-mentioned arteres and capillaries; they form frequent transverse anastomoses, but they also run chiefly in a radiating manner; they open, 1, into the *vasa vorticosa*, especially those veins which spring from the posterior surface of the iris; 2, into the *venæ ciliares posticæ*; and, 3 according to *Arnold* and *Retzius*, into the canal of *Schlemm*, a narrow circular canal situated between the most anterior border of the choroid and sclerotic, from which the *venulæ ciliares* arise, and conduct the blood outwards through the sclerotic.

The nerves of the tunica vasculosa are likewise very numerous, but are destined exclusively for the ciliary muscle and for the iris. The *nervuli ciliares* penetrate the sclerotic posteriorly with fifteen to eighteen trunklets, extend forwards in the outer lamella of the choroid, partly in furrows of the sclerotic, and divide several times in a forked manner, even before their entrance into the ciliary muscle. Here they break up into a rich and dense plexus, from which numerous filaments are distributed to the muscle and the cornea, and the remainder form the proper nerves of the iris. The latter nerves accompanying the blood-vessels, dividing repeatedly and forming anastomoses, especially in the situation of the annulus minor, until they reach the pupillary border, where they terminate, probably by free extremities, after repeated division and the formation of loops. The elements of all these nerves are moderately fine, and fine tubules (0·002‴ to 0·004‴) in the trunks, while in the iris they measure only 0·001‴ to 0·002‴ in diameter.

Fig. 223.

Nerves of one-half of the iris of a white rabbit; treated with caustic soda, and magnified 50 times. *a.* nervuli ciliares; *b.* anastomoses of the same at the border of the iris; *c.* larger arcuate connections of the same in the iris; *c′.* finer networks of the same in the inner parts; *d.* terminations of separate nervous filaments towards the exterior of the iris; *e.* sphincter pupillæ.

§ 226. *The Retina.*—The retina is the innermost of the five tunics of the eye-ball, and lies close upon the vascular tunic; in its proper nervous elements, however, it terminates at the *ora serrata* by an undulated border, *margo undulato-dentatus s. ora serrata retinæ*, where it is very intimately connected with the choroid on the one hand, and with the hyaloid membrane on the other. The retina is continued upon the ciliary part of the hyaloid membrane by a peculiar cellular layer, which will be spoken of hereafter.

The retina is a delicate membrane, almost perfectly transparent and clear when recent, but becoming, soon after death, whitish and opaque. It commences at the place of entrance of the optic nerve, being in part connected continuously with it. It possesses, at first, a thickness of 0·1‴, but soon becomes attenuated anteriorly to 0·06‴, till at last, near its anterior border, it measures only 0·04‴, terminating eventually by a very well defined edge. Notwithstanding the variations in its thickness, the following laminæ may be everywhere distinctly observed in the retina; they are enumerated in their order from without inwards: 1, *the layer of the rods and cones*; 2, *the granular layer*; 3, *the layer of grey nervous substance*; 4, *the expansion of the optic nerve*; and, 5, *the limitary membrane;* these layers, with the exception of the innermost lamina, which is everywhere equally thick, in general become thinner as they are traced forwards, corresponding to the diminished thickness of the retina as a whole.

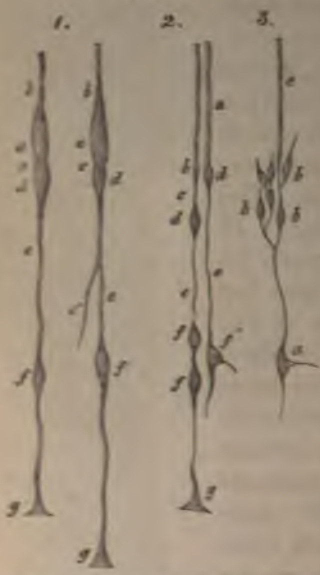
Fig. 224.

Perpendicular section of the human retina, made six lines anterior to the entrance of the optic nerve; magnified 350 times. 1. bacillar layer; 2. outer granular layer; 3. intermediate granular layer; 4. inner granular layer; 5. finely granular grey layer; 6. layer of nerve-cells; 7. fibres of the optic nerve; 8. membrana limitans.

1. The layer of the rods and cones, *stratum bacillorum s. membrana Jacobi* (fig. 224, 1), is a very remarkable layer, composed extremely regularly of innumerable strongly reflecting bodies cylindrical and conical in form. This stratum in animals has hitherto (except by *H. Müller, vide infra*) been quite incorrectly interpreted, and even in man it has been but very superficially known. It consists of two elements, the rods, *bacilli*, and the cones, which together form a single layer, whose thickness at the bottom of the eye is 0·036‴, further on diminishing to 0·030‴, and quite anteriorly becoming 0·028‴ in thickness. These elements are in general so arranged, that the more numerous rods are directed with their thick extremities outwards, while exactly the reverse is the case with the cones; and it is on this account that the latter, on imperfect investigation, appear to constitute an inner, special, narrower, layer situated between the inner extremities of the rods. The stratum bacillorum terminates internally with a pretty sharp line, the *limitary line* of the layer of rods, produced by numerous lateral projections of its elements abutting upon each other.

The rods, (fig. 225, 2), in man, are long, narrow, cylindrical bodies, which possess the same breadth throughout the whole thickness of the bacillar layer, and are continued from the inner end into the more internal layers of the retina, by means of a thin process, or the *filament of Müller*. Every rod is a cylinder, 0·028‴ to 0·036‴ long, 0·0008‴ broad, transversely truncated at the outer extremity, while the inner extremity tapers into a short point, 0·002‴ to 0·003‴ long, on the level of the limitary line of the bacillar layer, the point being frequently marked off from the rest of the rod by a delicate transverse line, and, therefore, more properly belonging to the filament of the rod. From this point the rod is continued by an extremely delicate filament, 0·0002‴ to 0·0003‴ thick, which becomes connected with the other elements of the retina in the manner to be afterwards described. —The substance of the rods is clear, homogeneous, with a slightly fatty lustre, very soft and pliant, but at the same time very brittle, so that it is only in perfectly fresh eyes that their true length can be recognised. Their delicacy is so great, that they undergo the most diverse alterations even in water, and become very difficult of recognition, curving into the form of hooks, rolling themselves up or becoming twisted, breaking into two or more pieces, and effusing clear drops, which are often found in enormous numbers upon the outer side of the retina, partly coming from the rods, partly from the ruptured pigment-cells of the choroid. One of the most usual alterations is, that the point, when it does not fall off, as is frequently the case, assumes an inflated varicose shape, becoming lancet-shaped, or even transformed into a globule, to which the filament is still attached; to this is frequently superadded a hook-like curve, or a slight swelling of the obtuse extremity of the rods. The rods are almost invariably much altered by re-agents, especially the rods themselves, which, notwithstanding their greater breadth, offer less resistance than the filaments. Ether and alcohol cause them to shrivel up, and render them scarcely recognisable, but they are not soluble either in these re-agents or in boiling water. In acetic acid of 10 per cent. they shorten instantaneously to a great degree, become distended at several places, and break up into transparent globules, which resist at first, but disappear after

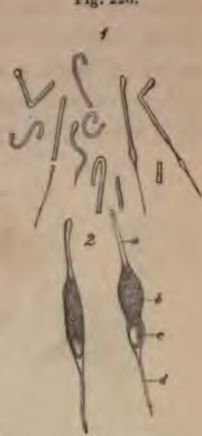
Fig. 225.



Elements of the bacillar layer in connection with the fibres of *Müller*. From the human retina, magnified 330 times. 1. cones, with fibres of *Müller*; *a.* thicker part of the cone, or proper cone; *b.* rods upon the same, one longer than the other; *c.* circular line at the inner end of the cone; *d.* nucleated swelling (cell-body) of the same already in the outer granular layer; *e.* fibre of *Müller*, into which it is continued; *e'.* lateral process from one of these fibres, passing inwards; *f.* granule (cell) of the inner granular layer; *g.* internal termination of the fibre of *Müller*. 2. rods with Müllerian fibres; *a.* rod; *b.* transverse line at its inner extremity; *c.* commencement of the filament of *Müller*; *d.* granules of the outer granular layer, one seated close to the rod; *e.* fibres of *Müller* in the intermediate granular layer; *f.* inner granules; *f'.* one of them with a lateral process; *g.* internal extremities of the fibres of *Müller*. 3. an inner granule, *a*, with three processes, of which the external one gives off branches, and supports several other granules, *b*, together with rods, of which only one is figured.

a time: (acetic acid, added to the rods of the frog's retina, causes them to swell up to two or three times their original size, and generally makes them roll up.) Concentrated acetic acid, as well as alkalies and mineral acids, dissolve them in a short time, while, on the other hand, diluted chromic acid is their best preservative, although it causes them to shrivel somewhat; with strong syrup and sulphuric acid they become red, while nitric acid and potash colour make them yellowish.—Taking all together, we may, perhaps, be allowed to regard the main constituent of those structures as a protein substance, and to look upon the rods themselves as delicate tubes, with viscid albuminoid contents.

Fig. 226.



Altered elements of the bacillar layer of the human retina. 1. rods detached from their filaments; variously notched, curved, and varicose, some of them broken; 2. two cones enlarged by chromic acid, showing their granular contents and shining nucleus, one of them with a shortened rod, the other with a rod swollen at the extremity; *a*. rods; *b*. cones; *c*. nucleus; *d*. fibres of *Müller* torn off. Magnified 350 times.

The cones (fig. 225, 1) are somewhat shorter rods, provided at their inner extremity with a conical or pyriform body, whose length (0·007‴ to 0·015‴) is equal to half the thickness of the bacillar layer, and measures 0·0020‴ to 0·0030‴ in breadth. Each of these cones consists, when fresh, of an almost homogeneous or extremely finely granular substance, with a slight lustre resembling that which forms the rods, except that it is clearer; it undergoes changes with almost the same facility, especially having a great tendency to swell up. The rods, which are continued externally from the cones, or the *cone-rods*, are sometimes just as long as the free rods, sometimes a little shorter. Unlike the rods, however, the cones are continued by a constricted portion into a pyriform swelling, 0·003‴ long, containing a cell-nucleus; this may be termed the cone-granule, and it lies in the outer granular layer, being united by a fine filament, similar to that of the rods, with the inner parts of the retina.

The rods and the cones are situated close to one another, and are arranged perpendicularly upon the retina, in the manner of palisades, the one extremity being directed outwards towards the choroid, the other towards the granular layer. The cones form an almost continuous layer (fig. 227, 2) in the neighbourhood of the yellow spot, the rods being arranged only in simple series between them; further forwards, however, they separate from each other, being distant at first, 0·002‴ to 0·003‴, and in the anterior parts of the retina they are even 0·004‴ to 0·005‴ apart (fig. 227, 3), and more rods are situated between them. The bacillar layer presents on its external aspect, when the outermost surface is brought into focus, roundish spaces more or less scattered, and filled with a clear uniting substance (which occurs elsewhere between the elements of this layer, and, in the horse, forms a sort of membrane, *Müller*); these spaces correspond to the cones, and in the centre of them a small dark circle appears, which is the terminal surface, or the apparent section of the rod seated upon the cone, while around the spaces the closely-crowded terminal surfaces of the proper rods are seen arranged in the manner of a mosaic, in simple, double, or multiple reticulated lines (fig. 227).

Fig. 227.

Bacillar layer seen from without. 1. at the yellow spot (only cones); 2. at the boundary of this spot; 3. from the middle of the retina; *a*. the cones, or the spaces corresponding to them; *b*. rods of the cones, the terminal surface of which is often situated deeper than the ends of the proper rods, *c*; mag. 350 times.

2. The *granular layer, stratum granulosum* (fig. 224), consists of clear granular bodies, which become dark in water and reflect the light pretty strongly. They are of round or oval form, 0·002‴ to 0·004‴ in size, sometimes look like free nuclei, sometimes like small cells almost completely filled with large nuclei; yet, according to my own observation, all would seem to belong to the latter category. I find, indeed, especially in chromic acid preparations, that very fine filaments, 0·0002‴ to 0·0003‴ thick, pass off regularly from each of these bodies in both directions, and that these filaments distinctly proceed, in many cases, from a pale contour around the cell, so that the whole bears a great resembance to a bi-polar ganglion cell in miniature. In man, the granules are everywhere arranged in two layers, an outer thicker, 0·018‴ to 0·026‴ (fig. 224, 2), and an inner thinner (fig. 224, 4) layer, 0·012‴ to 0·026‴, which are separated from each other by a clear layer, finely granulated and perpendicularly striated, 0·010‴ to 0·039‴ in thickness, which may be named the 'intermediate granular layer.' The outer granular layer consists of the proper outer granules (fig. 225, 2, *d*), connected with the filiform processes of the rods, the *rod-granules;* it also comprises the *cone-granules* (fig. 225, 1, *d*), already described. The granules of the inner lamina also, which are slightly larger than those of the outer layer, are connected both with the filaments of the rods and with those of the cones.

3. The *layer of grey cerebral substance* (fig. 224, 5, 6), extends

in a variable amount between the elements of the granular layer, from which it is rather sharply marked off, and the fibres of the optic nerve, from which it is less abruptly defined. It everywhere consists of two portions: 1, an *outer layer* finely granular and finely fibrillated (the layer of the grey nerve-fibres of *Pacini*); and, 2, of an *inner* lamina of *multipolar nerve-cells.* These have exactly the same characters as those of the brain, varying between 0·004‴ to 0·016‴ in size; they are mostly pyriform or roundish, or are drawn out into three to five angles; and they all possess one to six and even more long pale branched processes, first observed by *Bowman* (see *Lectures on the Eye*, p. 125), similar to those of the central nerve-cells. In all cases where these nerve-cells are seen upon perpendicular sections, one to two of these processes proceed outwards, and are lost in the inner granular layer (see below); while the others run horizontally, and are in part continued into genuine varicose optic fibres (*Corti, Remak, H. Müller*, and myself), in part connect together the more remote nerve-cells (*Corti*, confirmed in one instance by my own observation). The nuclei of these nerve-cells, which behave towards re-agents like those of the cells of the brain, measure 0·003‴ to 0·005‴, and generally possess a very distinct nucleolus. The *outer finely granular layer* of grey substance consists of a finely granular matrix, containing nothing else than the outer processes of the nerve-cells, together with the continuations of the fibres of *Müller* from the rods and cones into the innermost parts of the retina. This stratum measures 0·015‴ to 0·026‴ in thickness, while the nerve-cells form a layer 0·045″ to 0·052‴ thick at the yellow spot, where they are densest, and hence the layer of the cells decreases in thickness as it is traced forwards, until, at last, the cells occur quite isolated.

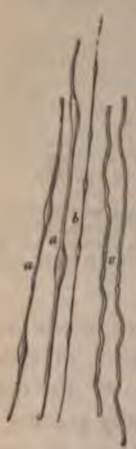
Fig. 228.

Two nerve-cells from the human retina, magnified 350 times. The smaller with two processes outwards, and only one varicose nerve-fibre arising from it; the other with a dividing process which passes into three nerve fibres, and two similar processes torn off.

4. Internal to the above layer follows the *expansion of the optic nerve* (fig. 225, 7). In its course from the optic commissure (see

p. 236) to the eye, this nerve has the same structure as an ordinary nerve, and its varicose dark-bordered fibres, 0·0005‴ to 0·002‴ thick, form a polygonal bundle, 0·048‴ to 0·064‴ in diameter, surrounded by an ordinary neurilemma. Arrived at the eye, the optic nerve loses its sheath in the sclerotic coat, which possesses an opening for the passage of the nerve, in the shape of a funnel with the base outwards; the inner neurilemma likewise terminates on the inner surface of the sclerotic, and also on the choroid, where it is connected with the above-mentioned lamina cribrosa; so that the tubules of the optic nerve, in their further course in the interior of the eye, pass on independently without their envelopes of connective tissue. Within the canal of the sclerotic, and up to the slight elevation, or *colliculus*, which it forms upon the inner surface of the retina in its passage forwards, the optic nerve is still white and furnished with dark-bordered tubules; but, from thence onwards, its elements, in man and in many animals, become quite clear, yellowish or greyish, and transparent, like the finest tubes in the central organs; they measure, on an average, no more than 0·0006‴ to 0·0008‴, while not a few only amount to 0·0002‴ to 0·0004‴; a few fibres, however, will be found which measure as much as 0·001‴ to 0·0015‴ or even 0·002‴. These tubules are distinguished from other pale terminations of nerves by the absence of nuclei in their course, by a somewhat stronger refracting power, and by the constant occurrence, in the dead body, of varicosities; the two latter characters lead us to regard the contents of the tubes as not being nervous medulla of the ordinary kind, but rather as of a partially semi-fluid nature, and perhaps somewhat fatty; so that we should class the nerve-fibres of the retina with the most delicate elements of the brain. I have not yet been able to demonstrate axial-fibres among the fibres of the retina; but, on the other hand, I believe I have distinguished an envelope on the larger varicosities, where they are ruptured, as frequently happens. In any case, the retinal fibres do not consist exclusively, indeed not to a preponderating degree, of ordinary white substance of *Schwann*, for even when they are treated very thoroughly with ether, they remain behind, narrower indeed, but more distinct and

Fig. 229.



Elements of the expansion of the human optic nerve, magnified 350 times. *a*, evident coarser nerve-tubes, with varicosities; *b*, a finer one; *c*, undulating pale fibres without varicosities, probably belonging to the filaments of *Müller*.

darker than previously. Fibres so treated swell up again in acetic acid, and are dissolved by alkalies; so that perhaps they consist chiefly of a nitrogenous substance.

With regard to the course of the nerve-fibres in the retina, this much is certain, that they radiate in all directions from the *colliculus nervi optici*, form a connected membranous expansion, which extends as far as the *ora serrata*, and present no interruption of any size except in the region of the yellow spot. In this proper nervous tunic, the nerve-fibres are collected together to found larger and smaller bundles, slightly compressed laterally, and measuring 0·01‴ to 0·012‴ broad, which either anastomose with each other at very acute angles, or run for long distances parallel to each other. At the yellow spot, only a small part of the optic fibres proceed directly to its inner end; much the larger portion of the fibres which are destined for the lateral parts of the spot, describe a series of curves, which take larger and larger sweeps as they are directed farther forwards. At the yellow spot itself, all these fibres lose themselves in its deeper portion, among the nerve-cells, so that there is here no superficial layer of optic fibres; the nerve-fibres of this spot most probably arise from the processes of its cells (*Remak*). External to the yellow spot, the fibres gradually become more spread out, and at last re-assume a straight course. As for the terminations of these nerves, the most recent investigations have rendered it more than probable that they *all* pass into the processes of the nerve-cells of the retina, a condition which, histologically speaking, would be better designated by saying that they all take their origin from these cells. The thickness of the layer of optic fibres measures 0·090‴, close to the entrance of the nerves; anteriorly, four to six lines from the colliculus, 0·028‴ to 0·036‴; quite in front, and at the border of the *macula lutea*, about 0·002‴; at the bottom of the eye, 0·036‴; two lines ex-

Fig. 230.

Distribution of the fibres at the entrance of the optic nerve and round the yellow spot. *a*. entrance of the optic nerve; *b*. yellow spot; *c*. arcuated fibres on both sides of it; *d*. arcuated fibres on its outer side; *ee*. radiating fibres of the optic nerve.

ternal to the yellow spot, 0·006‴ to 0·008‴; and near the *ora serrata*, 0·002‴.

5. The limitary membrane, *membrana limitans* (fig. 224, 8), is a delicate membrane, 0·0005‴ at the most in breadth, intimately united with the rest of the retina; it sometimes, however, becomes detached in large shreds on teasing out the retina, and on the employment of re-agents, and then it is seen to be perfectly structureless. It resists acids and alkalies for a long time, and resembles in other respects also the so-called *vitreous membranes*, such as the capsule of the lens.

The yellow spot is an elliptical part of the retina, 1·44‴ long, 0·36‴ broad, of a yellow or golden-yellow colour, whose inner extremity is distant 1·0‴ to 1·2‴ from the centre of the elevated circle formed by the entrance of the optic nerve. It possesses almost in the middle, but somewhat nearer to the inner end, an attenuated, colourless depressed spot, 0·08‴ to 0·1‴ in diameter. The *fold*, as it is called, which many authors assume to exist on the yellow-coloured part, and have named *plica centralis retinæ*, has been shown by *Virchow* and myself, as well as by others (our observations were on an executed criminal), not to be present in fresh eyes; but the *yellow colour* is seen in such cases, and is produced by a diffused pigment saturating all the parts of the retina, with the exception of the bacillar layer; the colour fades in a few days after keeping in alcohol and water. With reference to the structure of the yellow spot, it is wanting in a continuous layer of nerve-fibres, the superficial layer especially being absent: the nerve-cells lie in several strata immediately upon the membrana limitans, being placed close together like the cells of a pavement epithelium. Between these cells nerve-fibres run, others also entering from the circumference of the macula, and they are lost in them in a manner not yet accurately determined, probably in the nerve-cells. The finely granular layer of grey nervous substance (*Pacini's* 'fibre griggie'), is found on the outer parts of the yellow spot, but is absent in the middle. The two granular layers, and the intermediate granular lamina, occur over the whole of the macula, the fovea centralis excepted. The rods, as *Henle* discovered, and as I can confirm, are absent over the whole yellow spot, and are replaced by closely disposed cones, which are longer and narrower (0·002‴) than elsewhere, and bear a slender rod upon their outer side. I have observed filaments of the cones, or fibres of *Müller*, in all parts of the yellow spot, with the exception of the fovea centralis; I have not made any particular investigation of them in respect of their terminations, but they cannot be followed further than the inner granular layer, and are completely lost to view in the more internal strata. The thickness of the different layers of the yellow spot is the following: layer of the nerve-cells, 0·045‴ to 0·052‴; finely granular gray layer, 0·020‴; inner granular lamina, 0·026‴; intermediate granular lamina, 0·039‴; outer granular layer, 0·026‴; cones, 0·030‴.

Besides the expansion of the optic nerve, there exists in the retina another remarkable system of fibres, the *Müllerian or radiating fibre system*, which was first discovered in 1851 by *H. Müller* in the eyes of animals, and, in the following year, was shown by myself to be present in the human retina also.

Fig. 231.

Elements of the bacillar layer in connection with the fibres of *Müller*. From the human retina, magnified 350 times. 1. cones, with fibres of *Müller*; *a.* thicker part of the cone, or proper cone; *b.* rods upon the same, one longer than the other; *c.* circular line at the inner end of the cone; *d.* nucleated swelling (cell-body) of the same already in the outer granular layer; *e.* fibre of *Müller*, into which it is continued; *e′.* lateral process from one of these fibres, passing inwards; *f.* granule (cell) of the inner granular layer; *g.* internal termination of the fibre of *Müller*. 2. rods with Müllerian fibres; *a.* rod; *b.* transverse line at its inner extremity; *c.* commencement of the filament of *Müller*; *d.* granules of the outer granular layer, one seated close to the rod; *e.* fibres of *Müller* in the intermediate granular layer; *f.* inner granules; *f′.* one of them with a lateral process; *g.* internal extremities of the fibres of *Müller*. 3. an inner granule, *a*, with three processes, of which the external one gives off branches, and supports several other granules, *b*, together with rods, of which only one is figured.

Proceeding from the bacillar layer, in the description of the fibres of *Müller*, it is to be stated in the first place, that *every cone, and every rod is connected with the elements of the granular layer*. With regard to the cones, every cone-granule, which is to be regarded as a cell-body, is continued inwards by a fine pale filament, 0·0004‴ to 0·0006‴ in breadth, which, after it has traversed the outer granular layer and the intermediate granular lamina, terminates in the inner granular layer, becoming connected with a granule of this layer (fig. 231, 1, *f*). The rods also are connected in a similar manner with the outer and inner granules, though they present some peculiarities in this respect. Only a small portion of the rods, indeed, is connected at its inner extremity directly with a granule (fig. 231, 2, *d*) in the manner of the cones; for the greater part of them are first prolonged into a point (see above), which, after a course of 0·002‴ to 0·003‴, passes into an extremely delicate filament, 0·0002‴ to 0·0003‴ in diameter; the filaments being so delicate, that the slightest mechanical injury suffices to break them off close to their place of origin; whence it has arisen, that observers have hitherto known little beyond the proper rods, or when they have observed filaments attached to the rods, have regarded them as artificial products; these filaments, too, as well as the points of the rods, have been erroneously placed by all authors since *Hannover* on the outer side of the bacillar layer. After a course inwards of variable length, these fibres become connected with one of the ordinary granules of the outer granular layer; the filiform process of a rod attaching itself on the one side to a granule, while a similar filament goes off from the opposite inner side of it. In their further course, several of such filaments frequently, if not always, unite to form a somewhat thicker filament (fig. 231, 3), being occasionally interrupted by a granule; and this filament, like that of the cones, runs parallel to its fellows through the intermediate granular layer, which owes its radiated striation to these elements; then it enters the inner granular laminæ, with whose elements it likewise becomes connected. Indeed, I believe that I have found these filaments to be chiefly, if not exclusively united with the branched granules of this layer (fig. 231, 2 *f*, 3 *a*).

Fig. 232.

Perpendicular section of the human retina, near the entrance of the optic; magnified 350 times. 1. Bacillar layer; 2. outer granules; 3. intermediate granular layer; 4. inner granules; 5. finely granular gray layer; 6. simple layer of nerve-cells; 7. transverse section of the optic bundles; 8. Müllerian fibres, forming thin laminæ between the optic bundles; 9. termination of the same at 10, the membrana limitans. After a plate of the retina in ECKER's *Icones Phys.*

The radiating fibre system of the retina is by no means brought to an end by the passage of the filaments from the cones and rods into the outer and inner layers of granules, for the filaments are continued from hence through the entire innermost layers of the retina, and ultimately terminate at the membrana limitans in rather a peculiar manner. In this second half of their course, the fibres of *Müller* remain completely isolated and separated from one another, but become arranged, towards the expansion of the optic nerve, in a very definite manner, which is somewhat different in different regions of the eye. At the bottom of the eye, and so far as the optic bundles have only narrow fissure-shaped spaces between them, the fibres of *Müller* collect to form thin laminæ, which vary in extent according to the size of the meshes of the nervous plexus; in this form they are continued through the whole layer of the optic nerve-fibres, as may be seen both on transverse section through the optic expansion, or when viewed from the surface. Transverse sections (fig. 232) exhibit the flat bundles, some of them very thick, of the optic fibres as finely dotted columnar masses; while between them, forming coarser fibrous bundles, are seen the lamellæ of the fibres of *Müller* in profile; in the meshes of the nervous plexus, the terminations of these fibres are seen in the form of beautiful narrow rows of dark streaks and points, which in animals often appear directed in a regular penniform manner towards both sides. Further forwards, where the meshes of the nervous plexus become wider, the laminæ of the fibres of *Müller* increase more and more in thickness, and at last, at the most anterior part of the retina, they pass pretty close and parallel to each other towards the surface without presenting any other special arrangement; and they now appear on the surface as an almost continuous layer of dark points, this layer being interrupted only at the places where nervous bundles and large nerve-cells are situated.

Fig. 233.

From the human retina; magnified 350 times. *a*. A large nerve-cell; *b*. process from the same directed outwards, towards *c*. an internal nucleus (cell with a nucleus); *d*. filament of *Müller*, proceeding from the bacillar layer to this granule; *e*. second process of the nerve-cell, which is undoubtedly continued into one of the fibres of the optic nerve.

The *inner terminations* of the filaments of *Müller* pass through the layer of optic nerve-fibres, and reach the membrana limitans; but their arrangement here is somewhat difficult to ascertain, on account of their great delicacy and the ease with which they are injured. From all that I have seen, I think I am warranted in assuming, that the triangular truncated swellings, observed by *H. Müller* and previously by myself, and not the divisions and ramifications which also frequently occur, represent the true condition of these fibres at their terminations. These terminations, when a fold or a perpendicular section of a fresh retina is examined, appear as a clear border, 0·002‴ to 0·003‴ broad, between the membrana limitans and the expansion of the optic nerve; and this appearance has given rise, as I now find, to a belief in the presence of an epithelium in this situation. The clear globules, indeed, which *Bowman* (*Lect.*, fig. 15) describes, are nothing else than the inner terminations of the fibres of *Müller*, which, when they cover one another, and especially when they are distended by water, produce the appearance of roundish angular bodies, lying parallel to each other. Now, the truncated terminations of the fibres of *Müller* abut upon the outer surface of the membrana limitans, and pieces of the latter membrane, especially in chromic acid preparations, may not unfrequently be obtained in connection with these fibres; the connection of the two, however, is by no means intimate, for the radiating fibre-system can generally be detached with facility from the limitary membrane, especially in fresh preparations, or in such as have been treated with re-agents.

Fig. 234.

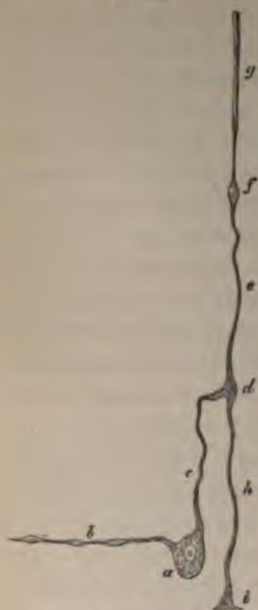


Diagram to represent the connection of the cells, rods, and fibres of *Müller*, according to my view of them. *a*. A nerve-cell; *b*. optic fibre; *c*. outer process of the cell, connected with an inner granule *d*: *e*. fibre of *Müller*, proceeding from this to an outer granule *f*, and thence to a rod *g*; *h*. internal extremity of the fibre of *Müller*, with the enlargement *i*.

The signification of this radiating fibre-system, and even its anatomical relations to the other elements of the retina, is still, in many respects, very obscure. This only is certain, as I formerly supposed (*Compt. Rend.*, 1853, Oct.), and as *H. Müller* and myself (see my *Gratulationsschrift an Tiedemann*, p. 12, and my *Micr. Anat.*, ii. 2, p. 703) have also recently demonstrated by direct observation, that *at the yellow spot, the fibres of Müller which leave the cones, enter into connection with one of the granules of the inner layer and with one of the nerve-cells of the retina.* It is very probable that at other places, filaments proceeding from the cones have similar connexions. We have no positive observations on the filaments of the rods; and it is not to be forgotten, that many histologists are inclined to dispute the nervous nature of many of the radiating elements of the retina.

The vessels of the retina are derived from the *art. centralis retinæ*, which, situated in the optic nerve, enters the eye, and commences its distribution from the middle of the colliculus by four or five main branches. Lying at first beneath the membrana limitans only, they pass through the lamina of nervous fibres into the layer of grey nervous substance, where they are distributed with beautiful arborescent ramifications as far as the ora serrata;

their terminal twigs form a wide network of very fine (0·002‴ to to 0·003‴) capillaries, which is chiefly seated in the layer of gray nervous substance, and partly, also, in the expansion of the optic nerve-fibres. The veins begin, in the lower animals, at the ora serrata by an incomplete circle, *circulus venosus retinæ*, run with their trunks parallel to the arteries, and collect in the *vena centralis*, which leaves the eye by the side of the artery. At the yellow spot there are no large vessels, but only numerous capillaries. I have never seen nerves on the vessels of the retina; on the other hand, I find here and there traces of an accompanying fibrous tissue on the outer side of the larger vessels, which is most closely allied to embryonic reticulated connective tissue.

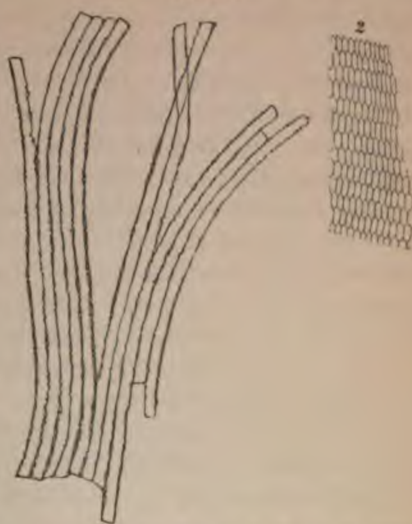
With regard to the function of the retinal elements, I refer the reader to my *Mikr. Anat.*, ii. 2, § 281, and will here make only the following remarks: I regard the rods and the cones as the only elements which can receive the impression of light; and I believe that they become endowed with this function through their connection with the nerve-cells, by means of the fibres of *Müller* acting as a conducting apparatus. The nerve-cells are to be looked upon as a flat and expanded ganglion, and, in all probability, as constituting the central organ of visual perception. This central apparatus and the brain are then connected by a second conducting apparatus, the optic fibres, which also have the function of placing the two retinæ in connection with each other. This view is based upon the demonstrated connection between the elements of the bacillar layer and the nerve-cells, upon the want of a connected layer of optic nerve-fibres at the yellow spot, and upon the absence of any perception of light at the colliculus. My opinion is also supported by the consideration, that we cannot possibly assign the faculty of perceiving light to the nerve-cells or to the granular layer, because the elements of these are super-imposed in many layers, especially at the yellow spot; and lastly, the peculiar local arrangement of the rods and cones, their size corresponding to the degree of the local sensibility of the retina, adds further confirmation to my opinion.

§ 227. The lens (*lens crystallina*) is a perfectly transparent body, connected at its posterior surface with the vitreous body, and laterally with the *zonula Zinnii*, or the termination of the hyaloid membrane. It is to be distinguished into the lens proper and its capsule.

The capsule of the lens (*capsula lentis*) consists of two elements, the *proper capsule* and the *epithelium*. The former is a perfectly structureless, transparent, and very elastic membrane, which surrounds the lens on all sides, like a mould, and separates it from the neighbouring structures. If a lens with its capsule be laid in water, a large quantity of the fluid is imbibed by the capsule, showing that such membranes, although apparently homogeneous, are yet readily permeable; we can, therefore, easily understand how the non-vascular lens can be supplied with nourishment by substances penetrating from without. The capsule of the lens measures, at its anterior wall, 0·005‴ to 0·008‴, but behind the attachment of the zonule of *Zinn*, where it suddenly becomes attenuated, only 0·002‴ to 0·003‴ in thickness; it can be readily torn, pierced, or cut, but opposes considerable resistance to a blunt instrument. If an uninjured capsule be pierced, it contracts, by virtue of its elasticity, to such a degree, that the lens not unfrequently passes out spontaneously. The capsule of the lens presents the same micro-chemical reactions as other vitreous membranes, except that, according to *Strahl* (*Arch. f. phys. Heilk*, 1852), it is dissolved by boiling in water.—The epithelium of the capsule of the lens is not situated on the outer side, as *Brücke* states, but upon the *inner* surface towards the lens, and lines the *anterior half* of the capsule as a simple layer of beautiful, clear, polygonal cells, 0·006‴ to 0·01‴, with round nuclei. At death, its elements readily separate from each other, and become distended into clear, spherical vesicles, many of which burst, and, together with some of the aqueous humour which has penetrated the capsule, constitute the so-called *liquor Morgagni*, which does not exist at all during life, when the epithelium is accurately adapted to the surface of the lens.

The lens itself consists throughout of long, flat, six-sided elements, 0·0025‴ to 0·005‴ broad, 0·0009‴ to 0·0014‴ thick, of clear appearance, great pliability and softness, and of considerable toughness. They are usually designated the *fibres* of the lens, but they are, in reality, delicate-walled tubes, containing a clear, viscid, albuminoid matter, which oozes out of them in large, clear, irregular drops when they are torn; such drops are always found in large quantities on examining the superficial fibres of the lens, so that these may be called with equal propriety, the *tubes* of the lens. In a micro-chemical point of view, these tubes are distinguished by the circumstance, that they become darker and more distinct in all substances which coagulate albumen; and hence reagents of this class are excellently adapted for the investigation of the lens, especially nitric acid, alcohol, creosote, and chromic acid; in caustic alkalies, on the other hand, they quickly dissolve, and are likewise very strongly acted upon by acetic acid. The tubes of the lens are firmer, narrower, and darker in the hard internal layers of the lens than in the softer external parts, where they cannot be demonstrated as true tubes. Their union is effected by simple apposition, their flat surfaces invariably lying parallel to the surface of the lens, and their attenuated borders locking regularly into each other; in the interior of the lens, therefore, as seen at fig. 235, 2, every tube is surrounded by six others, and their transverse sections present the appearance of a wall built of six-sided bricks. At their borders, and the surfaces of the borders, the tubes are generally somewhat uneven, or are even toothed (in animals, especially fish, very much so), so that the union of them, side to side, is more intimate than that of their broader surfaces; and it is on this account, also, that the lens breaks up into lamellæ more readily in the direction of the surface than in that of the thickness. In consideration of this peculiarity, we may ascribe a lamellated structure to the lens, which is the usual manner of describing it, and we may regard it as consisting, like an onion, of a series of laminæ, one enclosed within the other; we must not, however, lose sight of the fact, that these laminæ are not regularly-bounded layers, and that they never consist of a single layer of tubes; we must also remember, as being perhaps of great physiological importance, that the regularity of disposition in the elements of the lens is, properly speaking, still more observable in the direction of the thickness of the lens, than in the direction of its breadth. These elements, indeed, cover each other accurately throughout the whole lens; and the latter may equally well be regarded as consisting of very numerous perpendicular segments, each having the breadth of a single fibre.

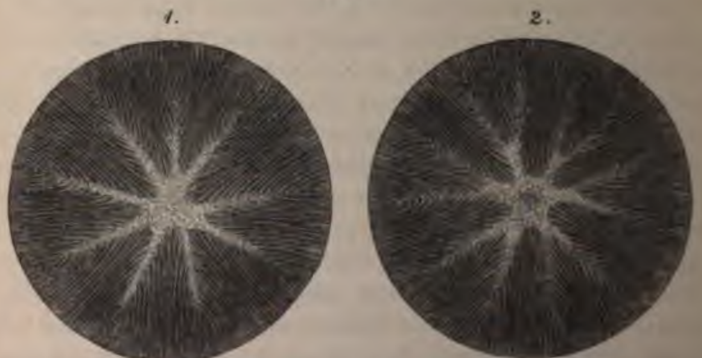
Fig. 235.



Lenticular tubes or fibres. 1. Of the ox, with slightly dentated margins; 2. transverse section of the lenticular tubes of man. Magnified 350 times.

The course of the tubes of the lens in the individual lamella is, in general, the following: they radiate, both in the superficial and in the deeper portions, from the axis of the lens towards the borders, and then curve round to the opposite (anterior or posterior) surface, but in such a manner that no fibre traverses the entire semi-circumference of the lamella; never reaches, for instance, from the middle of the anterior to the middle of the posterior surface. More accurately described, the tubes on the anterior and posterior surfaces of the lens do not go exactly to the middle, but terminate at two *stellate figures*, situated on the two aspects of the lamella. In the fœtus and in the newly-born infant, each of these stars, which are visible to the naked eye, has three rays, meeting each other regularly at angles of 120°; in the anterior star, two rays are situated below, one above; the reverse in the posterior star, which, accordingly, compared with the anterior, appears as if turned round through an angle of 60°. It will be seen, therefore, that the fibres of the lens, which proceed from the middle of the anterior star, run on the posterior side only as far as to the extremities of the three rays; and, *vice versâ*, those starting from the posterior pole do not reach the middle of the anterior star; the same condition is presented in all the tubes situated between these two points, none of them going quite round, and all those which lie in one layer being of equal length. In the adult, the nucleus of the lens presents exactly the same condition; but, on the other hand, in the superficial lamellæ, and on the surface itself, a more compound star is found, having from nine to sixteen

Fig. 236.



Lens of the adult, after *Arnold*, to show the stars. 1. Anterior surface; 2. posterior surface.

rays of various lengths, and rarely quite regular; still, however, certain main rays may even here be distinguished from the others. The course of the fibres necessarily becomes more complicated by this means; and the more so, as on such stars the fibres attached to the side of the rays converge in an arcuate manner, giving rise to a penniform or whorled appearance (*vortices lentis*). But, nevertheless, the essential points of the course of the fibres just described remain completely the same, seeing that in these more complex stars the rays of the anterior and posterior aspects do not correspond, and that no fibre goes from one pole to the other. In the stars, the substance of the lens is not formed of tubes as elsewhere, but consists of a material which is in part finely granular, in part homogeneous; and, therefore, it happens that, as the stars pass through all the laminæ, there exist three or more perpendicular, non-fibrillated planes (central planes, *Bowman*) in each half of the lens. The tubes of the lens become broader in the neighbourhood of the stars, but do not here coalesce with each other, for they terminate in clavate and fusiform enlargements of most diverse form, which often appear polygonal when seen from the surface (see my *Micr. Anat.*, ii. 2, fig. 416).

The fibres of the lens are sometimes finely striated longitudinally, and furnished with delicate, transverse lines, which cannot be referred either to fibres or to cells.—The superficial fibres of the lens are each provided, in the region of the equator of the lens, with a single, beautiful *nucleus*, which, the further we proceed inwards, becomes smaller and smaller, and at last disappears. *Thomas* found, on sections of dried lenses, two or three systems of concentric lines, which *Czermak* has recently explained in a way reconcileable with the structure of the lens.

§ 228. The vitreous body (*corpus vitreum*) completely fills the space between the lens and the retina, lying only loosely upon the proper retina, except at the place of entrance of the optic nerve, where the connection is somewhat more intimate; but, on the other hand, being very firmly connected with the *corona ciliaris* and the lens itself. The membrane enveloping the vitreous body (the *membrana hyaloidea*) occurs behind the *ora serrata* in the form of an extremely fine and delicate, clear pellicle, scarcely perceptible under the microscope; it is more readily visible at the bottom of the eye-ball, where it measures 0·004 of a millimetre (0·002'''), according to *H. Müller*. In front of the ora serrata, the hyaloid membrane becomes somewhat firmer, and proceeds, under the name *pars ciliaris hyaloideæ s. zonula Zinnii (lig. suspensorium lentis, Bowman)*, to the border of the lens, in order to coalesce with the capsule of it. During this course, it divides into an anterior and a posterior lamella, the latter of which coalesces with the capsule of the lens somewhat behind its border, but continues to be recognisable (*Arlt, H. Müller*) throughout the whole extent of the circular fossa of the vitreous body. The anterior lamella, connected with the ciliary processes, forms the *zonula*, in the more restricted sense of the term, and is inserted into the capsule somewhat in front of the border of the lens. Between the two lamellæ and the border of the lens there is seen on transverse sections a triangular space, completely encircling the lens—the *canalis Petiti*. This canal contains a little clear fluid, but is very narrow during life; for the zonule of *Zinn*, which forms its anterior wall, follows the plications of the ciliary processes in the form of a much-folded membrane, by which means it approaches very closely to the posterior wall in as many places as there are ciliary processes. These folds are also visible at the part where the zonula, after leaving the processes, passes over to the border of the lens as a part of the posterior wall of the *camera oculi posterior*; and thus we find that the zonula is attached, not in a straight but in a slightly wavy line, to the capsule of the lens, partly in front and partly behind the equator. According to *Finkbeiner*, the fine fibres, into which this membrane spreads itself out, may be followed in certain cases over the whole anterior wall of the capsule of the lens.

Fig. 237.

Sections of the vitreous humour hardened in chromic acid. *A*. Transverse section of a human eye, perpendicular to the axis of the optic nerve, with radiating striation in the vitreous humour. *B*. Section of the eye of a horse, made parallel to the axis of the optic nerve, and carried horizontally, to show the concentric stratification of the vitreous body.

With regard to the structure of the parts mentioned, much pains have been lately devoted to the examination of the proper vitreous body; and the truth has, perhaps, been pretty nearly arrived at. *Brücke's* opinion was, that the vitreous body consists of concentric lamellæ, like an onion, separated by a gelatinous fluid; but this view has been refuted by *Bowman*, who showed that the concentrated solution of acetate of lead, employed by *Brücke* for the exposition of these lamellæ, gave rise to the appearance of lamellation, not only at the surface of the vitreous body, but also on the surface of any section; but in no case did this method of investigation bring true lamellæ distinctly into view. There appear to be more facts in favour of *Hannover's* assertion (founded on an examination of the vitreous body of man, with the aid of chromic acid), that a number of partitions run from the surface to the axis of the vitreous humour, so that on a transverse section of the eye-ball, made from above downwards, numerous rays are seen to proceed from a central point, the whole structure resembling an orange. In mammalia, however, *Hannover* has seen concentric lamellæ, as in an onion (fig. 237, *B*). According to *Bowman* (*Lectures*, p. 97, fig. 5), the vitreous body of newly-born infants presents, in a well-marked degree, the radiated appearance described by *Hannover*, when it is prepared by chromic acid; but it is to be remarked, that *Bowman's* observations point to a somewhat different structure in the eye of the adult, for in chromic acid preparations of such an eye he finds some concentric lamellæ at the more external portion of the vitreous body, then very irregular radiating septa, and lastly, an irregular central cavity. When, moreover, it is considered, that these lamellæ, which appear when the eye is treated with chromic acid, cannot be demonstrated as true membranes, and that nothing is to be seen of them in the fresh vitreous body, the appearances produced by this second re-agent cannot be regarded as proving much.

A more correct view of the composition of the vitreous body appears to be obtained from the history of its development. It has long been known, that the vitreous body of the fœtus possesses vessels on its surface and in its interior; and from this it was inferred, that a tissue must be present for the support of these vessels, but until a short time ago, no one had endeavoured to obtain further information on this point by means of the microscope. *Bowman* (*Lectures*, p. 97, fig. 7, and p. 100) was the first to announce, that the vitreous body of the newly-born infant presents a very distinct and peculiar fibrous structure, consisting of a dense network of fibres, with dark nuclear corpuscles at the points of interlacement, so that the structure bears a considerable resemblance to the enamel organ (*i. e.*, to its gelatinous connective tissue) of the embryonic dental sac. Some recent observations of *Virchow* accord pretty closely with this view. According to this author, the vitreous body of a pig-embryo, four inches long, consists of a homogeneous, muciferous substance, slightly striated here and there, and having round, nucleated, granular cells scattered through it at regular distances. At the circumference of the body is seen a fine membrane, with very beautiful vascular networks and a finely fibrous, areolar meshwork, which contains nuclei at the knots, and likewise encloses in its meshes gelatinous mucus with round cells. On account of this structure, and because he has also found mucus in the vitreous body of the adult, *Virchow* believes himself warranted in classifying the tissue of the embryonic *corpus vitreum* with what he calls 'mucous tissue,' but which I regard as embryonic connective tissue (see § 23); and he further assumes, that in the course of development the structure undergoes a change, by which the cells perish and the intercellular substance alone remains. For my own part, an examination of the vitreous body in the embryoes of man and of animals, as well as in children and young animals, has revealed to me nothing else than a homogeneous, muciferous matrix, with numerous, granular, nucleated cells, round or elongated, and measuring 0·004‴ to 0·01‴, distributed pretty regularly through it at distances of 0·01‴ to 0·02‴, or even 0·03‴. I have also observed stellate anastomosing cells, but always on the outer side only of the hyaloid membrane, and these were readily demonstrated to be developing capillaries, obtaining a connection with the well-known vessels external to the hyaloid, as soon as those vessels began to convey blood. I have never seen with the microscope any positive trace of the membranes which are described by *Hannover* in the vitreous humour; and yet I venture to assert, that such membranes, if they existed, must be just as easy of recognition in their folds as the extremely delicate hyaloid membrane itself. In the vitreous body of the adult, only the homogeneous matrix was found to remain, the cells having disappeared. I have often, however, met with scanty and indistinct remains of these cells, especially in the parts of the vitreous humour adjoining the lens and the hyaloid membrane.—From these observations, I draw the conclusion, that the vitreous body does possess, at an early period, a kind of structure which most resembles embryonic connective tissue; but that subsequently, at least in its inner parts, every trace of this structure disappears, so that it comes to consist exclusively of a more or less consistent mucus (see § 23).

Zonula Zinnii.—At the ora serrata, the vitreous body comes into intimate contact with the retina, and this again with the choroid, so that it is extremely difficult to elucidate the true condition of the nature of the structure which has been above described as the *zonule of Zinn.* If it be exposed from without, black pigment from the ciliary process always remains adherent to it at certain spots, and often for a considerable extent. If places be chosen for examination where this is not the case, the zonula is found to have an outermost greyish layer, which extends exactly to the point where the ciliary processes join with the zonula, and then terminates anteriorly with a slightly-toothed, irregular border. In the anterior portions especially, we may always recognise with the microscope, even when the zone looks quite clear, a considerable number of pale pigment cells of the choroid, arranged in rows, and situated more especially in the folds which contained the ciliary processes; they give the whole of this grey layer a striated appearance. Next, internally, lies a simple layer of clear, often very pale, nucleated cells, polygonal or cylindrical, and measuring 0·006‴ to 0·012‴. This layer, however, is never complete, but always becomes partially detached, along with the ciliary processes and cells, from it, as had already been observed here by *Henle* and others. This layer of cells belongs to the retina, and not to the hyaloid membrane, and is most fitly designated by the name *pars ciliaris retinæ*. It is the immediate continuation of the retina, though it contains none of the essential parts of this membrane, and its connection with it is probably only owing to the circumstance, that its rudiment in the fœtus is common to it and to the retina; it passes forwards between the *corona ciliaris* and the zonule of *Zinn*, is intimately connected with both, and, leaving the zonule of *Zinn*, terminates where the ciliary processes border upon the iris.

Apart from these layers, the *zonula* is a thin, transparent, but pretty firm membrane, which extends from the *ora serrata retinæ* to the border of the lens, and appears as the continuation of the hyaloid membrane. It consists of peculiar pale fibres, well described by *Henle*, which resemble certain forms of reticulate connective tissue, except that they are more rigid, generally present no distinct fibrillæ, and become less swollen in acetic acid. These fibres are very fine, resembling in part the fibrils of connective tissue, at the point of their origin at the outer side of the hyaloid membrane; they are here, however, somewhat behind the *ora serrata retinæ*, but in most intimate connection with the hyaloid; they then run forwards, forming a layer which is at first loose, but afterwards becomes denser and denser, increasing in thickness up to 0·004‴ or even 0·01‴ and more, with frequent divisions and anastomoses. The fibres and their divisions run, for the most part, parallel to each other, till, at the free part of the zonula, they form a perfectly connected layer (the individual bundles being always separable, however), and then coalesce with the capsule of the lens. From the *ora serrata* to the commencement of *Petit's* canal, a hyaloid membrane is no longer distinguishable with the zonular fibres; on the other hand, at the above-mentioned canal, where the substance of the vitreous body separates from the fibrous lamina, a limitary membrane, even more delicate than formerly, makes its appearance, and forming the posterior wall of *Petit's* canal, extends up to the border of the lens; from this point it is no longer traceable as a special membrane, the vitreous body becoming most intimately united with the posterior lamina of the capsule of the lens.

Of the authors who have recently investigated the vitreous body, *Finkbeiner*, employing corrosive sublimate, obtains results somewhat similar to those of *Hannover*; but, in several respects, his account does not appear satisfactory.—*Doncan*, on the other hand, adopts views which are nearly identical with those of *Virchow* and myself. He lays special stress on the fact that a fluid escapes from the cut surface of the vitreous body, leaving a compacter substance behind. He finds no trace of the membranes described by *Hannover*, either in the fresh *corpus vitreum*, nor after treatment with acetate of lead and chromic acid. This author is uncertain whether the striated, radiating appearance observed in chromic acid preparations indicates a separation of the vitreous body into definite zones, or whether it is only an artificial effect. *Doncan* regards the peculiar motion of *muscæ volitantes* as being opposed to *Hannover's* theory of the structure of the vitreous body. Although not in a position to demonstrate his views conclusively, *Doncan* is inclined to regard this body as being made up of definite spaces containing a fluid; and he concludes, from the motion of muscæ volitantes, and from other considerations, that these spaces are disposed vertically in the hinder part of the organ, and transversely in the anterior portion.

In the neighbourhood of the entrance of the optic nerve, *H. Müller* has found, on the hyaloid membrane, a somewhat knotted network with a few nuclei, probably the remains of the fœtal vessels. A similar structure is found in the eyes of animals, on the obliterated hyaloid artery.

B. ACCESSORY ORGANS.

§ 229. The Eye-lids receive their shape from two structures, named the *cartilages* of the eye-lids, or *tarsi*, which are thin, semilunar plates, pliant but very elastic, and fastened together, both internally and externally, by fibrous ligaments (the *lig. tarsi*). The histological relation of these plates is with firm connective tissue, although they occasionally contain a certain number of small cartilage cells; they measure 0·3‴ to 0·4‴ in thickness, and their fibres run chiefly parallel to their borders; they are covered externally by the *orbicularis palpebrarum* and the *skin*, and internally by the *conjunctiva*. The external skin is here very thin ($\frac{1}{5}$‴ to $\frac{1}{8}$‴), and the subcutaneous connective tissue is thin, loose, and free from fat; its epidermis is delicate (0·055‴ to 0·058‴ in thickness), and it is provided with short papillæ ($\frac{1}{66}$‴ to $\frac{1}{40}$‴); it possesses, however, small sudoriparous glands ($\frac{1}{10}'''$ to $\frac{1}{12}'''$) in its whole extent, and almost invariably is furnished with numerous small hairs, many of which are without sebaceous glands. These hairs present a more considerable development at the border of the tarsi, where they form the *eye-lashes*, and are then provided with small sebaceous glands. The *Meibomian glands* completely agree with sebaceous glands in their structure and secretion, but are somewhat different in form. They are twenty to forty in number, and form elongated, white racemes, situated parallel to one another in the tarsal cartilages, so that the axis of each gland is at right angles with the long axis of the eye-lids. These glands may be seen without trouble on the everted eye-lid, occupying a portion only of the breadth of the tarsi; each of them consists of a straight excretory duct, 0·04''' to 0·05''' wide, opening on the inner margin of the free border of the eye-lid; at the aperture it is lined by ordinary epidermis with mucous and horny layers, while further inwards it presents the same condition as in the sebaceous glands. It is beset in its whole course with short, pedunculated gland-vesicles, round or pyriform, isolated or grouped. These acini measure from 0·04''' to 0·07''' and 0·1''' in diameter, and in them a continual production of round fatty cells goes on, in the manner already described for the sebaceous glands (§ 74). The cells measure 0·005''' to 0·01''', and are only distinguished from ordinary sebaceous cells by the circumstance that their fat-globules do not usually coalesce into large drops, but remain separate. Whilst these cells are moving towards the excretory duct, they gradually break down into a creamy whitish substance composed of fat-globules, forming the so-called *lema s. sebum palpebrale.*—The *orbicularis palpebrarum* muscle is composed of transversely striated, but rather thin and pale muscular fibres, and lies immediately beneath the skin, while on its internal aspect, it is separated from the tarsi by a layer of loose connective tissue containing a little fat; hence it can be readily raised in a fold from the tarsi, along with the skin. It is only towards the free border of the eye-lid that this muscle is more firmly connected with the tarsus, and it here presents a bundle situated at the extreme edge, and separated from the rest of the muscle by the follicles of the eye-lashes; this has been named the ciliary muscle (*musculus ciliaris, Riolan*), of which some few bundles lie behind the ducts of the Meibomian glands.

The mucous membrane of the eye-ball, or *conjunctiva*, commences at the free border of the eye-lid as an immediate continuation of the external skin, lines the posterior surfaces of the eye-lids, and is then reflected upon the eye-ball, and covers the most anterior part of the sclerotic and the whole of the cornea. The *conjunctiva palpebrarum* is a reddish membrane, 0·12‴ to 0·16‴ thick, which is very intimately connected with the posterior surface of the tarsus, and consists of a dense layer of connective tissue corresponding to the cutis, and measuring 0·08‴ to 0·11‴ in thickness; on this is placed a lamellated epithelium, 0·04‴ thick, with elongated cells in the deeper portions, and on the surface, polygonal, slightly flattened, nucleated cells, which have no cilia, as far as I have been able to observe, on the human conjunctiva. Papillæ also, similar to those of the cutis, exist on the conjunctiva of the eye-lids, some of them small and more cylindrical, others being larger, up to $\frac{1}{10}$‴ in length, and of a wart-like or fungiform shape; these larger papillæ are found especially in the neighbourhood of the reflexion of the membrane, where the whole structure becomes increased in thickness. At the flexure itself, *C. Krause*, *Sappey*, and *W. Krause* describe small racemose mucous glands, $\frac{1}{16}$‴ to $\frac{1}{3}$‴ in diameter, which *W. Krause* has counted to the number of forty-two in the upper lid, between two and six only in the lower. The *conjunctiva scleroticæ* is white, less dense and thick than that of the lids, well supplied with fine elastic fibres, and is loosely attached to the sclerotic by a large quantity of submucous connective tissue, containing more or less fat-cells. Papillæ and glands are completely absent from this membrane, when it is traced past the flexure; but, on the other hand, the epithelium is well developed; while on the *conjunctiva corneæ*, beneath the epithelium, we may frequently observe a very distinct, structureless, narrow band, forming the outermost lamina of the proper mucous membrane. At the edge of the cornea, the sclerotic conjunctiva, especially in old people, forms a slight circular swelling, $\frac{1}{2}$ to 1 line broad, the *annulus conjunctivæ*, which extends for a little way over the cornea, at its upper margin particularly. We have already spoken of the conjunctiva of the cornea, and have only now to make mention of the *plica semilunaris*, or third eye-lid, at the inner angle of the eye. This is a simple fold of the sclerotic conjunctiva, the anterior portion forming a rounded elevation, the *caruncula lacrymalis*, which contains about a dozen fine hairs, with an equal number of racemose sebaceous glands, $\frac{1}{5}$‴ to $\frac{1}{4}$‴, lying around them, and surrounded by numerous fat-cells.

The *lacrymal apparatus* consists essentially of the *lacrymal glands* — a number of compound racemose glands of various sizes arranged in two groups, which constitute the so-called upper and lower glands; in their structure, they exhibit larger and smaller lobules, with roundish gland-vesicles (0·02‴ to 0·04‴ wide), and in these respects they completely agree with the salivary and mucous glands (see §§ 133 and 135). Their excretory ducts, six to twelve in number, penetrate the conjunctiva in the fold formed by this membrane, between the outer part of the upper eye-lid and the ball; they are extremely fine canals, composed of connective tissue with some nuclei and elastic fibres, and of a cylindrical epithelium; the ducts are extremely difficult of demonstration in man, but may be readily seen in animals, in the ox, for example. —Just as simply constructed as the excretory ducts of the lacrymal glands are the passages which convey away the tears; they consist of a dense connective tissue with numerous networks of fine elastic fibres, especially in the lacrymal canals, and this forms a continuation of the conjunctiva into the mucous membrane of the nasal cavity; it is lined by an epithelium, of the lamellated pavement variety upon the lacrymal canals, as in the conjunctiva; but on the lacrymal sac and duct, furnished with cilia, as in the nasal cavity.—The muscles of the eye and eye-lids, as well as the muscle of *Horner* (*tensor tarsi*), all consist of transversely striated muscular fibres, and neither they nor their tendons present any deviation from similar structures in the trunk and extremities. The *fascia bulbi oculi s. Tenoni* is a true fibrous membrane. The trochlea is chiefly composed of dense connective tissue, in which but few cartilage-cells are demonstrable.

The *vessels* of the accessory organs described in this section present but little that is worthy of notice. Apart from the muscles and the skin, they are most numerous in the conjunctiva palpebrarum, where they pass into the papillæ; they are also pretty numerous in the lacrymal glands and in the caruncula lacrymalis. The conjunctiva scleroticæ also possesses many vessels, and the Meibomian glands are surrounded by some few within the tarsi. Except in the skin of the eye-lids, *lymphatic* vessels have only been demonstrated in the *conjunctiva scleroticæ,* where they were seen by *Arnold* to form a fine network at the border of the cornea, becoming more scattered externally, and then passing outwards by several trunklets. The eye-lids and the conjunctiva generally are rich in *nerves*; but their arrangement has only been examined at all narrowly in the conjunctiva. In man, I find here, as in the external skin, *terminal plexuses*, with numerous divisions into tubes, 0·001‴ to 0·006‴ thick, as far as to the border of the cornea;

there are also pretty distinct indications of loops and free terminations. Peculiar nervous coils, measuring 0·02‴ to 0·028‴, were also observed in one case towards the conjunctiva of the eye-lids; into these a single nerve-fibre generally entered, while the issuing fibres numbered from two to four (see my *Micr. Anat.*, ii. 1, p. 31, fig. 13, A. 3). The distribution of the nerves in the lacrymal apparatus is entirely unknown.

According to a very recent statement of *H. Müller*, the *musculus orbitalis* of certain mammalia is composed of unstriated fibres, and it presents the same structure, also, in the orbital cavity of man.

§ 230. *Physiological Remarks.*—The eye-ball is not developed, as a whole, from a single point, but is formed by the meeting together of several formations; one of them proceeding from the central nervous system, a second from the skin, and a third from the parts situated between these two. In the embryo of the chick, the primitive *optic vesicles* spring from the first cerebral vesicle or anterior brain, and are visible at the commencement of the second day as two protrusions, which are at first sessile, but subsequently provided with a hollow peduncle, the rudiment of the optic nerve. At the commencement of the third day, the formation of the crystalline lens begins from the skin of the face covering this vesicle, the epidermis becoming thickened internally, and introverted in such a way, that the anterior wall of the primitive eye-vesicle is likewise pushed inwards and applied to the posterior wall, so that the cavity of the vesicle completely disappears. A secondary eye-vesicle is thus formed, which accurately embraces the lens after the manner of a mould, the lens having become, in the meanwhile, separated from the remaining epidermis by a constriction, and lying beneath the surface. Subsequently, however, the vitreous body is developed between the lens and the eye-vesicle in a special new cavity. It is not yet ascertained how this structure originates; but it is most probable, as *Schöler* states, that it likewise grows inwards from the skin, beginning beneath and behind the lens, and being concerned along with it in the introversion of the primitive eye-vesicle. According to *Remak*, the retina is formed from the inner thicker wall of the inverted or secondary eye-vesicle; while from the outer thinner wall the choroid coat arises, and subsequently the iris, from its anterior border. The sclerotic and cornea become applied from without, when the eye-ball has reached this stage; and the former is, in part, a production from the skin.

The vessels which occur in the eye of the fœtus, even in the transparent media, present many points of interest. The vitreous body possesses on its outer surface, between the hyaloid membrane and the retina, a pretty wide vascular network, which is supplied by branches distributed from the arteria centralis retinæ at its entrance into the eye; anteriorly at the border of the lens, this network forms a circular vessel upon the zonule of *Zinn*, the *circulus arteriosus Mascagnii,* from which vessels then proceed to the membrana capsulo-pupillaris, to be immediately described. Besides these vessels, a special *arteria hyaloidea*, likewise derived from the arteria centralis retinæ, passes through the vitreous body in the so-called hyaloid canal directly to the lens, and ends in a multitude of branches, which join at very acute angles, in a membrane lying close upon the posterior wall of the capsule of the lens. This membrane is, indeed, a part of an *outer vascular capsule*, which at first accurately surrounds the lens; and whose anterior wall is supplied by continuations of the hyaloid artery round the border of the lens, together with branches which unite with this vessel from the *circulus arteriosus Mascagnii*, and the anterior border of the uvea. Subsequently, when the lens retracts from the cornea on which it was at first closely applied, and the iris buds forth from the border of the uvea, the anterior wall of the vascular capsule of the lens is divided into two parts; a middle anterior part, which proceeds from the pupillary margin of the iris, and is connected with this membrane by vessels so as to close the pupil (*membrana pupillaris*); and, secondly, an outer posterior part, which passes backwards from the same point to the border of the lens (*membrana capsulo-pupillaris*). The more the iris and the chambers of the eye are developed and the lens recedes, the more distinct this latter portion of the vascular capsule becomes; till at last it appears as a delicate membrane traversing the posterior chamber of the aqueous humour. The venous blood of all the parts mentioned, is returned by the veins of the iris, and the blood of the outer surface of the vitreous body returns also by the veins of the retina, and perhaps, also, by a *vena hyaloidea* (whose existence is doubted by many authors, and never observed by myself), which is said to take the same course as the arteries. With regard to the genetical signification of the vascular capsule, nothing has hitherto been ascertained concerning it. I found it composed of a homogeneous tissue, with a few interspersed cells; and I regard it as a structure corresponding to the cutis, which becomes detached from the general integument along with a part of the epidermis, during the formation of the lens, and thus comes to lie within the eye. The vitreous body may, then, be looked upon in the light of undeveloped subcutaneous connective tissue; and the more so since all the subcutaneous connective tissue of the embryo is at one period perfectly gelatinous (as I have shown in § 29 of this work, 3rd Germ. ed.); again, the enamel organ, which also belongs to this category, bears a striking resemblance to the mucous tissue of the vitreous body, both in appearance and consistence.

With regard to the histological development of the eye, the following remarks only require to be made here. At an early period, the eye consists in all its parts of homogeneous formative-cells, which in the course of time become transformed into the different tissues. In the fibrous coat, the cells become converted, in the second and third months, into connective tissue, in the manner before described (§ 26); and at the same time, the cornea and sclerotic exhibit a distinction, they being at first quite the same in external appearance, and constituting only a single coat. In the uvea, the cells are mostly employed in the formation of the vessels; another part of them is converted into the inner and outer pigment layers, pigment granules being deposited at the commencement of the third month; while a third part develops into the muscles, nerves, epithelial and connective tissues of this coat. In the retina, the development of the nerve-cells and of the so-called 'granules' from the embryonic cells, can be readily traced. I have observed the cones to develop in the same way; and in the frog I believe I am warranted in assuming that the rods are nothing but elongated cells (see my *Micr. Anat.*, ii., 2, p. 730); on the other hand, the formation of the rods in mammalia, and that of the nerve-fibres themselves, have not yet been followed. The lens, lastly, consists at its origin entirely of cells, which, in the course of time, pass into fibres. The fibres of the lens of the fœtus, and of that of the

Fig. 238.

Fibres of the lens of an adult in process of development; magnified 350 times. 1. a young fibre with the nucleus at the anterior extremity; seen from the surface and from the side. 2. a similar fibre, in which the elongation forwards is commencing. 3. a rather long fibre, elongated towards both extremities; a. its posterior, b. its anterior extremity.

child, each presents only a single nucleus; and, from this fact, I concur with *H. Meyer* in drawing the conclusion, that each of the fibres is developed from a single cell. These nuclei, considered in their totality, form a thin layer, proceeding from the margin of the lens through its anterior half, and having a slight convexity forwards (nuclear zone of *Meyer*); while in the inner parts, the nuclei are smaller, as if in the act of dissolution, whence it may be concluded that the lens grows from without by the apposition of thin laminæ. The cells which go to form the tubules of the lens are those which are situated at the anterior half of the capsule; and, from what I have seen, the starting-point in the formation of the elements of the lens is at the border of the organ. Even in the lens of the adult, as I have shown (*Micr. Anat.*, ii., 2, p. 730, *et seq.*), all stages of development in the fibres of the lens (fig. 238) may be seen at the border of the organ, and we can at the same time convince ourselves that the fibres really arise from the cells of the epithelium.

Investigation of the Organ of Vision.—The fibrous coat of the eye is to be examined in its fresh state, and in softened sections of dried preparations; the latter especially give good views of the cornea, and of its transition into the sclerotic. If, after the removal of the vitreous body and lens, the iris and chorioidea be dried together, their connection with each other and with the fibrous tunic, may also be studied. In order to see the *nerves and vessels of the cornea*, the cornea of a fresh eye is to be cut off, along with the border of the sclerotic, by means of a circular section, and the whole is then to be divided into three or four segments; they should then be notched at the cut edges, in order to lay them flat, moistened with the aqueous humour, and covered with a glass plate. The nervous trunks, which are mostly dark in this situation, are first to be sought with low magnifying powers at the border of the cornea, and then traced onwards with stronger lenses. The nerves are most beautiful in the eye of the rabbit, where I can recognise their trunks with the naked eye; but they can also, as a rule, be readily found in other eyes, though they are always difficult to trace towards the middle. If the epithelium is turbid, it must be removed by caustic soda, which does not at first alter the nerves. The vessels are mostly found filled with blood, and present no difficulties. The epithelium of the cornea is seen very well from the surface on sections of dried preparations, and also by scraping it off. The membrane of *Demours* is very distinct in sections, and sometimes its epithelium, too; or the latter may be very well seen from the surface, or on detached shreds of the membrane. The transition of this membrane into the *ligamentum iridis pectinatum*, is recognised upon sections and by careful dissection. In the latter case, the iris and the choroid must be detached, and the inner wall of the canal of *Schlemm* is to be carefully removed along with them; portions of the membrane of *Demours* may then often be separated without difficulty. The uvea presents but little difficulty. The pigment-cells of the stroma, with their processes and the internal pigment, are easily seen, the latter at the edge of a folded piece of the membrane, and on carefully detached portions. A fresh eye is necessary for the examination of the ciliary muscle, as its elements soon cease to be recognisable. The muscles of the iris are to be studied in a blue eye, especially in that of a child after the removal of the posterior pigment; also in the eyes of white rabbits, in which the *sphincter pupillæ* is readily seen without further trouble on the addition of acetic acid. The same preparation may be employed for the examination of the nerves of the iris, but a perfectly fresh eye and diluted caustic soda are indispensable conditions in the investigation. Many observations on the uvea are facilitated by blanching it with chlorine-water, as is recommended by *Wittich*. The retina must be examined, when fresh, from the surface, upon perpendicular sections, and upon the borders of folds; it should be studied first with aqueous humour, and without the employment of a covering-glass; slight compression and teasing of it out may also be practised in its subsequent examination. Chromic acid preparations are here very important. Chromic acid, indeed, partially alters the rods, but by no means invariably, and it preserves other parts so much the better; indeed, without this re-agent, *Müller* and myself could never have arrived at the results above given, although *Hannover* erroneously objects to its use on account of its action on the rods. The best way of using chromic acid is to apply it immediately to a perfectly fresh retina, and to follow all the stages of its action step by step. If a very diluted solution be employed, the elements are very little altered, and can be readily isolated; if the solution is somewhat concentrated, sections can be made, more especially through the retina; and without these, no complete view of the structure of this membrane can be obtained. I make them by spreading out a piece of retina upon a slip of glass, with a solution of chromic acid, in such a manner that it lies flat and cannot float. These sections are to be made as fine as possible with a sharp convex scalpel or razor, and they should be taken from the edge of a cut surface by pressure from above; this is easily done after a little practice. It is good, however, to guide the cutting scalpel by means of a scalpel-handle brought under it with the other hand, until it is immediately over the margin of the retina. Such sections are more especially to be made in the region of the yellow spot, and afterwards in other places, both in a longitudinal and transverse direction; when successful, they should present but a few layers of the elements. The individual laminæ are very sharply marked off from each other, and they are first to be studied on these sections; afterwards the several layers may be carefully teased out or rendered more transparent with caustic soda; though this re-agent is not generally of much use, because it causes the elements to become exceedingly pale. The hyaloid membrane is always easily detached posteriorly from the retina along with the vitreous body, and may be recognised in every eye on sections of the surface of the vitreous body under the microscope; in its folds it may be partially distinguished by the naked eye. The *zonula Zinnii*, on the other hand, is, in fresh eyes, always covered by detached pigment and colourless epithelium from the ciliary processes, and at its posterior end it is overlapped by the retina, so that it cannot be well seen here; but it is readily traced at its free anterior part. Nevertheless, without other preparation than removing as much as possible of the adhering structures with a brush, pretty distinct views of the zonula may be obtained. Sections of the zonula, separated from the vitreous body, should also be examined on their inner and outer surfaces, and preparations may also be made by teasing out the component structures. Borders of folds should also be studied, particularly folds of the inner surface, which may be obtained by a little care in the whole extent of the zonula, and at the place of its attachment to the retina. The zonula may be obtained in connection with the hyaloid, and isolated from the retina and from the cells of the ciliary process, in half-putrid eyes, and after maceration of the vitreous body; such preparations are especially adapted to show that the zonule is a part of the hyaloid, as well as to exhibit the manner in which its fibres appear, and are distributed. For the study of the fibres of the zonule, I may also recommend chromic acid preparations, in which they become quite dark and shining, almost like elastic fibres. The capsule of the lens and the epithelium present no difficulties. The tubules composing the lens are, when fresh, very transparent, but become extremely distinct in diluted chromic acid. Sections of the lens are readily obtained from preparations which have been hardened in alcohol or chromic acid, or been simply dried; and such sections can be restored to their transparency by acetic acid.—The accessory organs of the eye do not require to be specially noticed; but it may be remarked with reference to the Meibomian glands, that they can be best seen on cleanly dissected tarsi which have been treated with acetic acid and alkalies; and they are to be studied also on longitudinal and transverse sections of preparations which have been dried.

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II.—OF THE ORGAN OF HEARING.

§ 231. The organ of hearing consists of the *proper sensory parts*, with the expansion of the auditory nerve, which are contained in the bony substance of the labyrinth; together with special accessory apparatus, the *outer and middle ear*, which are principally destined for the reception and conduction of the undulations of sound.

§ 232. *External and Middle Ear.*—The auricle and the cartilaginous external auditory meatus are supported by the cartilage of the ear (*cartilago auris*), $\frac{1}{8}'''$ to $1'''$ in thickness, which is very pliant when covered with its perichondrium, but is otherwise very brittle. This cartilage, whose form is well known, approximates in its structure to the yellow or reticulate cartilage, yet it is distinguished from it by a considerable preponderance of large cartilage-cells, $0{\cdot}01'''$ in size, in the striated matrix. It is covered by the *external skin*, which scarcely contains any fat, except in the lobules, and is closely adherent to the cartilage on the concave side of the pinna, where it is characterised by its great abundance of *glands*. The glands are, first, ordinary *sebaceous glands*, which are most developed in the concha and scaphoid fossa, attaining here a diameter of $\frac{1}{4}'''$ to $1'''$; secondly, small *sudoriparous glands*, $\frac{1}{16}'''$, on the convex side of the pinna; lastly, the ceruminous glands, which have been previously described (§ 72), in the cartilaginous external auditory passage itself. In the latter situation, the cutis measures $\frac{1}{5}'''$ to $\frac{1}{8}'''$, without the epidermis, which is $\frac{1}{75}'''$ to $\frac{1}{50}'''$ in thickness; besides the ceruminous glands, it possesses hairs and sebaceous glands, lying in a dense subcutaneous tissue; in the *meatus osseus*, on the other hand, the skin is very delicate, studded up to the membrana tympani with numerous fine papillæ (*Gerlach*), and very firmly blended with the periosteum of the meatus.

The middle ear, together with the ossicula, tendons and nerves contained in it, is lined in all its spaces by a delicate mucous membrane, which is more fragile in the mastoid cells, upon the ossicula (when it also forms the *membrana obturatoria stapedis*), and upon the membrana tympani, than in the accessory cavities of the nose; it is thickest in the Eustachian tube. Its epithelium is, at the places last mentioned, laminated and provided with cilia, $0{\cdot}024'''$ thick; this is transformed in the tympanic cavity into a thin ciliated layer of pavement-cells, in one or two strata, which extends to the accessory cavities; this, however, is replaced at the tympanic membrane by a simple non-ciliated pavement epithelium, as we have lately found in an executed criminal. The membrane of the tympanum consists of a middle fibrous plate, which commences at the *sulcus tympanicus* in connection with the periosteum lining the tympanum and the meatus osseus, and connected also with the cutis lining the latter. At its origin, this fibrous plate is composed of a dense band of fibres, the majority of which are circular, and form the so-called *annulus cartilagineus*; the outer surface of this membrane is formed by radiating fibres, diverging from the handle of the malleus which is inserted here; the inner surface is made up of more circular elements. The two layers may be separated from each other, and they are both composed of bundles of connective tissue with plasmatic cells. On the outer aspect of the membrana tympani, a delicate covering of epidermis is prolonged from the external auditory meatus, along with a process from the corium (*Arnold*, *v. Tröltsch*), but this latter can scarcely be regarded as a complete covering (*Gerlach*).

The *ossicula auditus* chiefly consist of spongy osseous substance with a delicate compact cortex, and their articulations and ligaments are exact representations in miniature—even down to a layer of cartilage in a single lamina—of similar structures elsewhere. Their muscles are transversely striped like those of the external ear.—The Eustachian tube is mainly composed of a cartilaginous basis, which in its structure approaches the true cartilages, but generally has a pale fibrous matrix; in this cartilaginous part, especially towards its mouth, the tube is provided with numerous racemose mucous glands of exactly the same nature as those of the pharynx, the mucous membrane of which is continued without any perceptible boundary into that of the tube.—The external ear is provided with *vessels* and *nerves* in the same manner as the outer skin. In the middle ear, the mucous membrane of the walls of the tympanic cavity and tuba Eustachii are especially rich in vessels. The membrana tympani is also plentifully supplied; and here the largest arteries and veins run along the handle of the malleus, in the outer layer of cutis, and form arterial and venous vascular rings at the circumference of the membrane, besides ramifying abundantly in the mucous membrane. The nerves are chiefly from the fifth pair, and from the glosso-pharyngeal; taken as a whole, they ramify scantily in the mucous membrane. Their terminations are unknown; except that the tympanic nerve has been found to contain numerous large ganglionic cells, isolated or in groups. On the membrana tympani, the chief nervous trunk, which lies in the outer layer of cutis (from the vagus (?), according to *Sappey*), descends from the periosteum at the upper border of the meatus, gives off branches in the neighbourhood of the *processus brevis*, and then proceeds in the direction of the handle of the malleus and may be followed beneath it, dividing into fine twigs (*v. Tröltsch*). Pale nerve-fibres have been seen by *Gerlach* in the mucous covering of the tympanic membrane.

§ 233. The *vestibule* and the *osseous semi-circular canals* are covered on their inner surface by an extremely thin periosteum, consisting of rigid connective tissue, with fine fibres and numerous nuclei, but without any elastic elements; it resembles in many respects the fibrous structures of the inner wall of the canal of *Schlemm* in the eye. Upon the surface of this periosteum, is seated a simple pavement epithelium of delicate polygonal nucleated cells, measuring 0·007‴ to 0·009‴, which are concerned with the scanty vessels of the periosteum in the formation of the *perilympha s. aqua Cotunni*, which fills the osseous labyrinth. — By the junction of the periosteum of the labyrinth with the lining of the tympanic cavity, is produced the structure known as the *membrana tympani secundaria*, which, like the true tympanic membrane, is composed of a middle fibrous layer containing vessels and a few nervous filaments, together with two epithelial layers.

The two membranous saccules and the membranous canals, contained in the interior of the vestibule, and of the osseous semicircular canals, all present essentially the same structure. Their walls are firm transparent and elastic, and of some thickness (0·012‴ to 0·015‴ in the canals, 0·016‴ in the saccules) in proportion to the diminutiveness of the parts; they present externally a membrane composed of fine reticulate fibres, resembling very much the *lamina fusca* or outer pigment layer of the choroid, and even possessing, like it, some irregularly scattered brownish pigment cells. Then follows a transparent vitreous membrane, 0·004‴ to 0·008‴ in thickness, and sharply bounded internally; here and there this membrane exhibits a distinct delicate longitudinal striation, and a number of elongated nuclei are always to be seen on the addition of acetic acid; hence it is probably not to be classed with the *membranæ propriæ*, such as the capsule of the lens for instance, though it approaches these membranes very much, even in its chemical reactions. Lastly, the innermost layer is a simple pavement epithelium, 0·003‴ thick, breaking down readily into its elements, with polygonal cells of various sizes (0·004‴ to 0·008‴); it lines all the spaces mentioned, and encloses a fluid named *endo-lympha s. aquula vitrea auditiva:* in this fluid of the ear of fishes, *Barruel* has established the occurrence of mucus.

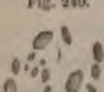
The vessels of the membranous labyrinth are pretty numerous, and form small arteries and veins, which are distributed in numerous capillary networks upon the fibrous and vitreous coats, and most abundantly in the neighbourhood of the terminations of the nerves. Of such terminations, only those of the auditory nerve are known; this nerve gives off the *nervus vestibuli* for the supply of the three membranous canals, and of the *sacculus ellipticus*, while the round sacculus is supplied by a branch from the cochlear nerve. In the canals, the nerves are distributed only upon the ampullæ, in each of which, as *Steifensand* has shown, they enter into an incurvation or duplicature of its wall upon the concave side of the canal, and in this way a transverse projection is produced on the inner aspect of the wall, occupying about one-third of the circumference. The nerves divide within these folds, first into two main branches, which diverge towards the two borders of them, and then break up in the vitreous coat of the ampulla into dense tufts of smaller branches, which anastomose with each other in various ways, and form fine twigs containing from two to ten primitive fibres, 0·001‴ to 0·0015‴ thick; these twigs pass through the membrane of the ampullæ and end in the epithelium, which is here thicker than elsewhere (*Reich*, *M. Schultze*, and myself); their mode of termination is not yet sufficiently understood. The distribution of the nerves is similar in the saccules, except that it occupies a larger space, and the projection of the wall in which the nerves are situated is much less marked here than in the ampullæ. At the place of the nervous expansion, there exists in each of the saccules a chalk-white and sharply bounded spot, readily visible to the naked eye; it is fixed on the internal wall of a very clear membrane, 0·01‴ thick, perhaps of the nature of an epithelium.

Fig. 239.

Transverse section of a semicircular canal. *a.* fibrous coat with nuclei; *b.* homogeneous membrane; *c* epithelium. From the calf. Mag. 250 diameters.

This is the so-called *otoconia* of *Breschet*, or *otolith*, and is composed of innumerable round elongated corpuscles, often in the form of double pointed, probably six-sided, columns; these particles are suspended in a homogeneous substance, and measure 0·0004‴ to 0·005‴ in length, and the larger ones are 0·001‴ to 0·002‴ in breadth. They consist of carbonate of lime, and when this is removed, they leave behind, it is said, a small quantity of organic matter, but I have not yet succeeded in observing it.

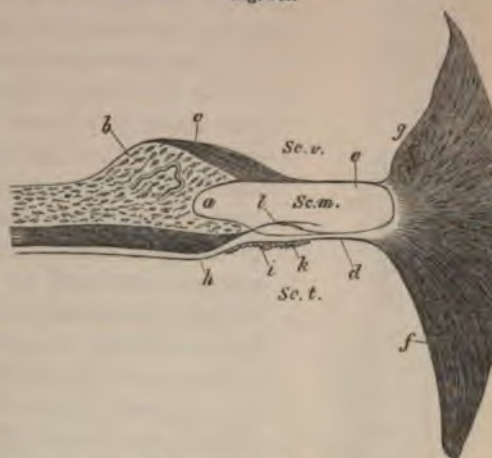
Fig. 240.



Otolithes from the internal ear of the calf. Mag. 350 times.

§ 234. *Cochlea.*—The canal of the cochlea, filled with the fluid of the labyrinth, contains not only the two well-known spiral cavities, but also a third narrower space, which I propose to call the *scala media*, situated in great measure within the *lamina spiralis*. This is placed between the *lamina spiralis membranacea* or *basilar membrana* of *Claudius*, on the one hand, and a peculiar second lamina, which should be named the *membrana Cortii*, on the other hand. (This structure was first indicated by *Corti*, though it was not thoroughly understood by him). At the beginning of the scala media in the vestibule, and at its termination in the cupola of the cochlea, its relations are not yet well understood. The *scalæ vestibuli* and *tympani*, apart from the portions of them which adjoin the walls of the scala media, are lined by a periosteum dotted with pigment, which is in all respects constructed like that of the vestibule, and is also extended over a part of the *lamina spiralis ossea*. This periosteum is covered by an epithelium 0·005‴ in thickness, with delicate flat polygonal cells of 0·007‴ to 0·009‴ in diameter, often presenting a little pigment in the lower animals; and this epithelium extends over those portions of the scalæ which adjoin the basilar membrane and the *membrana Cortii*.—The most important part of the cochlea is the *lamina spiralis*, taken in its widest sense, as including the membrane of *Corti* and the *scala media*. In its osseous zone, it contains anastomosing canals, with narrow intervals between them; these are for the reception of the cochlear nerves, and unite towards the free border of the lamina to form a fissure-like space, so that here the bony spiral lamina really consists of two plates. The membranous zone

Fig. 241.



Transverse section through the spiral lamella of the first turn of the cochlea. From the ox; magnified 100 diameters. *Sc. t. Scala tympani*; *Sc. v. Scala vestibuli*; *Sc. m. Scala media*; *a. sulcus spiralis*; *b.* teeth of the first series; *c. membrana Cortii*, its thicker part; *d. membrana basilaris*; *e. Corti's* membrane, its thinner part; *f. lig. spirale*; *g. stria vascularis*; *h.* nervous expansion in the zona ossea; *i. vas spirale internum*; *k.* layer of corpuscles of connective tissue, with varicose processes from them; *l.* organ of *Corti*, only just indicated.—The epithelium is nowhere shown in this figure.

Fig. 242.

Perpendicular section of the lamina spiralis, six lines distant from its commencement, magnified about 225 times. From the cat or dog. The epithelial layer which covers the upper and under surface is omitted. *a*. periosteum of the zona spiralis ossea; *b*. the two layers of the lamina spiralis ossea near the free border; *c*, *c'*, *c''*. termination of the auditory nerve; *d-w*. lamina spiralis membranacea; *d-w'*. *zona denticulata*; *d-d'-f*. *habenula sulcata*; *d*. spot where the periosteum becomes thickened; *e*. nuclei in the grooves of the habenula sulcata; *f-g*. teeth of the first series; *g-f-h*. *sulcus s. semicanalis spiralis*; *h*. lower wall of the same; *k*. epithelial cells at the entrance of the semi-canal; *h-w'* *habenula denticulata*; *h-m*. apparent teeth; *n-t*. teeth of the second series; *n-p*. posterior segment of the same; *o*. enlargement with a nucleus on it; *p-q*. and *q-r*. articular pieces; *r-t*. anterior segment of the second series; *s*, *s*, *s*. three cylindrical cells, seated upon it; *b-v*. membrane which covers the habenula denticulata; *u*. one of the epithelial cells beneath it; *w-w'*. zona pectinata; *x*. periosteum which fixes the lamina spiralis (*musc. cochlearis*, *Todd* and *Bowman*); *y*. *vas spirale internum*; *z*. its inner coat. After *Corti*.

of the lamina spiralis has a constant breadth of 0·2‴, and divides into the two membranes already mentioned with the intermediate space, the scala media, between them. Each of these parts deserves a more particular description.

The lamina spiralis membranacea, in its more restricted sense (excluding the membrana Cortii), is also called the *basilar membrane*, and may best be divided with *Corti* into two portions, a *zona denticulata*, and a *zona pectinata*. The former of these occupies about the inner two-thirds, the latter about the outer third of the breadth of the membranous lamina spiralis; they are both distinguished by a great complexity of structure, which has recently been the subject of a remarkable work by *Corti*; and, since this author, additional observations have been lately made by myself, *Claudius*, *Reissner*, *Böttcher*, and *M. Schultze*. Figs. 242, 243, 244, and 245, will assist in the explanation of these difficult structures; the two figures which have been taken from *Corti* are indeed faulty in several respects, but they are indispensably necessary to the right understanding of the nomenclature adopted by this writer.

A. The *zona denticulata* of the basilar membrane (figs. 242, 243, *d-v*) is again to be resolved into two portions, the one internal, the *habenula interna s. sulcata* (*d-g*), the other external, the *habenula externa s. denticulata* (*h-t*). The former is immediately prolonged (at the point marked *d*) from the periosteum of the osseous zone, on that aspect of it only which looks towards the scala tympani; it decreases in breadth and thickness from the beginning to the end of the cochlear canal. In the first and second turns of the cochlea, its under surface lies in the place of the periosteum, on the outer edge of the osseous spire; but in the last half-turn, it is only limited by the nervous expansion, so that the habenula sulcata is here, in strictness, a part of the membranous spire. I find the habenula sulcata to consist of a dense connective tissue, almost homogeneous, but having a few stellate plasmatic cells and scattered capillaries. On its upper surface, at the outer margin, there is found an uninterrupted series of elongated projections, transparent and with a peculiar lustre, somewhat expanded at their extremities; these are the so-called 'teeth of the first series,' which, according to *Corti*, measure 0·02‴ long, 0·004‴ to 0·005‴ broad, and 0·003‴ thick, at their commencement in the first turn of the cochlea, while in the last turn they exhibit a length of only 0·015‴, and a breadth of 0·003‴. These teeth project, with their one side free, into the scala vestibuli, and with their points, to which the membrana Cortii is attached, arch over the commencement of the habenula externa, so that between the two there results a pretty deep furrow, opening externally into the scala media, the *semicanalis spiralis* of *Huschke*; in the ox, this remains open for 0·04‴ in depth (fig. 241). Towards the axis of the cochlea, the above-mentioned teeth are directly continued into similar elongated prominences or ribs (fig. 243), which occasionally coalesce or separate in pairs, and still further inwards break up into shorter and smaller pieces, at first elongated, and afterwards round. In the longitudinal and transverse grooves, which are found between these ribs and prominences, and the teeth, there exists a simple series of dark shining corpuscles (figs. 242, 243, *e*), roundish or elongated, and measuring 0·0015‴ to 0·002‴ in

Fig. 243.

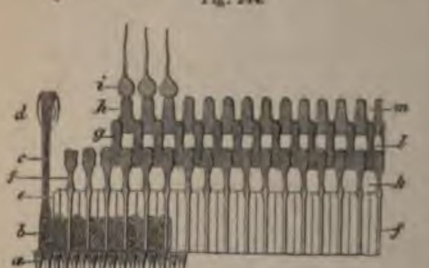
Surface of the lamina spiralis membrana; the surface which is turned towards the scala vestibuli; magnified 225 diameters. The lettering is partly the same as that of fig. 242. *α α*. cylindrical prominences of the *habenula sulcata*; *β*. place where a tooth of the first series took origin; *γ*. foramina between the *dents apparents*; *δ*. the anterior portion of a tooth of the second series, turned down; *ε*. a similar tooth in situ, without its epithelial cells; *ζ*. a similar tooth with only its lowest epithelial cell; *η*. another with the two lowest cells; *θ*. striæ or slight prominences in the *zona pectinata*; *κ*. periosteum giving attachment to the lamina spiralis, with spaces, *λ*, between the fibrous bundles. After *Corti*.

size, which are shown to be nuclei by the addition of acetic acid; by means of this re-agent, small nucleated cells also occasionally become distinct in the pale and swollen teeth and ribs; these parts, as well as those to be immediately described, are to be regarded as belonging to the group of connective tissues.

The *habenula externa s. denticulata* (fig. 242, *h-t*) arises immediately from the *habenula sulcata* above described, beneath the base of the teeth of the first series; it forms, at first, the floor of the above-mentioned spiral furrow. Its thickness amounts, in most places, to only 0·001‴ (about the same as that of the other membranous lamellæ, especially the *zona pectinata*), and its breadth increases towards the cupola of the cochlea in proportion as that of the habenula sulcata diminishes; thus it measures at first only 0·05‴, but at the apex of the cochlea 0·1‴ in breadth. With regard to its structure, it continues to present, upon the side next the scala vestibuli, a certain number of prominences, while towards the scala tympani it is perfectly smooth and even. The prominences when traced from within outwards, present the following arrangement. First of all come the so-called 'apparent teeth' (*dents apparents, Corti*), forming a close series of elongated projections, 0·01‴ long, 0·02‴ broad, which are separated from each other by shallow grooves; they become slightly raised towards their outer extremity, and then suddenly slope down again. Taken together, these apparent teeth produce a structure which I have designated the *habenula perforata;* in the first turn of the cochlea, they lie beneath the teeth of the first series, still upon the *zona ossea*, while in the second and third turns, on the other hand, they lie external to them, and with their under surface in immediate contact with the nerves; they exhibit fissures or canal-like spaces between their outer extremities, and these are found not only in the first half-turn of the cochlea, as *Corti* assumed, but throughout the whole extent of the spire. External to these 'apparent teeth,' there follow in equal numbers the *teeth of the second series* (figs. 242, 243, *n-t*), very curious structures, discovered and named by *Corti*, and regarded by him as direct out-growths of the basilar membrane. I have shown, however, that they are in connection with the *cochlear nerves*, and I have designated them in their totality, the 'organ of *Corti*,' and their separate elements, the 'Cortian fibres.'

According to my most recent observations, compared with those of *Corti*, *Claudius*, *Böttcher*, and *M. Schultze*, the organ of *Corti*, as far as we are warranted in making any positive statement about it, presents the following arrangement: In the neighbourhood of the foramina of the habenula perforata (*mihi*) peculiar rod-like structures take their origin; these are the Cortian fibres, which taken together form a sort of membrane in the whole length of the *lamina basilaris*, lying near that lamina, and being fastened to it at its outer end. The membrane formed by the Cortian fibres is convex in the middle (rising up towards the membrana Cortii), and may best be compared to a broad but short bridge. More narrowly investigated, this peculiar apparatus is found to consist of two sorts of pieces, the inner and outer Cortian fibres, which although agreeing with each other in many particulars, yet differ in many respects, especially in their numbers; for the inner fibres are more numerous than the outer (as *Claudius* first pointed out), so that three of the inner fibres correspond to two of the outer (fig. 244, *a*, *b*). The inner fibres commence in a very regular series near the foramina of the habenula perforata, where they are about 0·0015‴ to 0·002‴ in breadth, and soon present on the side turned towards the basilar membrane a nucleated swelling, which is produced, according to *Schultze*, only by a cell lying on them: they then run outwardly, with a gentle slope upwards, parallel to each other, but separated by fissure-shaped interspaces, and end by broadened (0·0024‴) extremities which lie close together, and are more raised than the other parts of the fibre; these were erroneously regarded by *Corti* as being separate pieces, and were named by him, *Coins articulaires internes*. Upon these follow the outer Cortian fibres, beginning by a slight annular constriction, and another similar enlargement of the fibre up to 0·0035‴ (*Coins articulaires externes, Corti*); these fibres are fewer in number and broader than the inner series (fig. 244, *b*). The outer Cortian fibres bend downwards back again towards the basilar membrane, become narrowed in the middle, and expanded at their further extremities into a triangular end, on the under side of which also, I have often found a nucleated swelling; by these ends the fibres come into contact with the basilar membrane, but are always easily separable from it, and have no intimate connexion whatever with it. The entire length of a Cortian fibre, including the outer and inner portions (the former of which is usually somewhat the longer), amounts to 0·037‴ to 0·050‴; and as for their other properties, they have not the smallest resemblance chemically to the *lamina spiralis membranacea*, with which they have been classed by *Corti* and some other recent writers; for, on the very contrary, they are tender and easily destroyed fabrics, dissolving instantly in dilute caustic soda and potass, and destroyed also by moderately diluted hydrochloric acid. Acetic acid of moderate strength causes these fibres, in the ox, to swell up at once and to become granular in their interior, and then quickly dissolves them; it has the same action in the Cortian fibres of the cat, but more slowly. Alcohol, ether, chromic acid, concentrated solutions of salt or sugar, cause the fibres to shrink, and when water is then added they swell up somewhat; these substances, however, have certainly a less harmful influence on the structures in question than on the rods of the retina, and the fibres may be preserved for a long time in them; this, however, we know to be the case even with the very delicate rods of the retina, especially in careful chromic acid preparations, and furnishes no proof of the greater resistance of the Cortian fibres, as has been assumed by several modern writers. In considering the nature of the fibres of *Corti*, the fact is not without significance, that they occasionally exhibit varicosities (see my *Micr. Anat.*, ii., 2, fig. 435, 3), so that a delicate envelope and darker contents may be distinguished in them.—Besides these fibres, the organ of *Corti* possesses some other remarkable structures, the chief of which are the 'pedunculated cells' of *Corti*, and a special apparatus discovered by myself (see *Micr. Anat.*, ii., 2, p. 756), which I will call the *lamina reticularis cochleæ*. This last has been strangely overlooked by all recent writers with the exception of *Schultze*, although it is to be seen in almost every cochlea, and often in mere fragments of it; it is, however, in the accurate study of its arrangement, one of the most difficult parts of the organ to investigate. This is not the place to describe this apparatus in much detail, so that I shall refer to a drawing of it, made from a very excellent preparation (fig. 244), and shall only mention briefly its component parts. These are—1. A short transparent plate (*e*), with delicately defined partitions, corresponding in number to the inner Cortian fibres. This plate is attached to the line

Fig. 244.



Lamina reticularis cochlea (*mihi*). From the ox; magnified 350 diameters. *a*. outer ends of the inner Cortian fibres (*Coins articulaires internes, Corti*); *b*. beginning of the outer Cortian fibres (*Coins articulaires externes, Corti*), seen through the lamina reticularis; *c*. an outer Cortian fibre; *d*. end of the same with the nucleated swelling; *e*. transparent plate of the *lamina reticularis*; *f*. straight rod; *g*. inner articulating segment; *h*. outer articulating segment; *i*, terminal segment; *k*. foramina of the first; *l*. of the second; *m*. of the third row. The great delicacy and elegance of these structures is only partially rendered in this drawing.

of demarcation between the inner and outer Cortian fibres, and appears to be intimately connected with the inner ones, and is also united, or at least closely adjacent, to the structure to be immediately described. 2. A reticular lamella in a more restricted sense, composed of four series of segments; *a.* of elongated straight rods (*f*), slightly swollen at their end, whose number is the half of that of the partitions of the transparent plate, and which also set out from the line of union between the two series of Cortian fibres, lying above the outer fibres; *b.* of smaller pieces in the form of an hour-glass (*g*), lying between the anterior ends of the rods, and which I will call the 'inner articulating segments'; *c.* of more conical bodies (*h*) situated between the ends of those last mentioned, which may be named the 'outer articulating segments'; *d.* of a row of terminal segments (*i*), which in many preparations have the form shown in fig. 244, while in others they are rectangular pieces lying very closely upon each other: in either case, there are seen to project from these segments filiform processes of an uncertain nature. These segments will be found at one time conjoined so as to give the appearance of a single plate, but at other times they occur distinctly separated from each other. Between the segments of each row are found a series of apertures, regularly disposed (*k*, *l*, *m*), which I have named the 'inner, middle, and outer foramina of the lamina reticularis.' As to the size of the perforated plate which is thus produced, the best notion will be given by stating, that the external ends of the outer Cortian fibres lie in a line with the third row of foramina; and as to the nature of the lamina reticularis considered as a whole, I can only say that it appears to have in every respect the same signification as the Cortian fibres, except that I have never observed nuclei or varicosities on its component parts; on the other hand, a variety of curves may often be seen, like those which frequently exist on the fibres of *Corti*.

The 'pedunculated cells' of *Corti* are the most delicate and transient structures of the organ of *Corti*, as appears from the fact, that none of the more recent observers, with the exception of *M. Schultze*, have properly recognized them. They are situated in three rows (those of one row alternating, it appears to me, with those of the other), always over the foramina of the membrana reticularis; they have a pyriform outline, more or less stretched, and are finely granular, with a conspicuous nucleus; each of them is prolonged internally into a fine filiform process. I formerly believed that these processes became united with the Cortian fibres, or rather with the reticulated lamina, but I have now satisfied myself that they pass through the foramina of the lamina reticularis, and lead into small spindle-shaped cells lying beneath the organ of *Corti*, between it and the membrana basilaris. These cells are probably connected with the terminations of the auditory nerve, of which more hereafter.

B. The *zona pectinata* of *Todd* and *Bowman* (figs. 242, 243, *w′*-*w*) is the outer portion of the lamina spiralis membranacea, or basilar membrane; it is quite smooth on both its aspects, and is fastened externally to a projection of the outer wall of the cochlear canal. This is a perfectly homogeneous lamella which appears to be closely ribbed (except at its borders) in the transverse direction of the cochlear canal, and thus acquires a fibrous aspect. Externally, a narrow tract of this lamella appears perforated, and it is here continued into a peculiar fibrous substance (fig. 241, *f*), which springs from the walls of the cochlea along a minute osseous ridge, the *lamina spiralis accessoria* of *Huscke*. This fibrous substance is described by *Todd* and *Bowman* as the *musculus cochlearis*, but as I find it nothing but a form of nucleated connective tissue, I prefer to designate it the *ligamentum spirale*.

The *membrane of Corti*, which forms the opposite boundary of the scala media (the basilar membrane limiting it on the other side), is extremely difficult to see in its natural situation. Figure 241 is carefully drawn from the best transverse section of the cochlea which I have been able to obtain, yet I will not venture to maintain that it affords a correct representation in all its parts. According to my inquiries up to the present time, the membrana Cortii consists of a special striated lamella, an epithelium, and a delicate stratum of ordinary connective tissue. The epithelium and connective tissue seem to be prolongations of the lining of the scala vestibuli, stretching between the ligamentum spirale on the one hand, and the teeth of the first series and the osseous zone on the other hand; underneath this prolongation, and therefore looking towards the scala media, is the striated lamella, which alone constitutes the membrane seen and described by *Corti*. In spite of the fact that this membrane may be isolated in every preparation with the greatest ease, still no observer has yet made out its relations in a satisfactory way: in figure 245, I therefore give a transverse section of the membrana Cortii from the first turn of the cochlea in the ox. Here it will be seen, that this structure is very thick (up to 0·02‴, in a zone only 0·06‴ broad) in about the half of its breadth, while the other portion runs off into quite a

Fig. 245.

The striated lamella of the *membrana Cortii*, seen on transverse section in the ear of the ox. Viewed by *Nachet's* lens No. 3, and eye-piece No. 1. *a*. the thicker portion of the membrane.

thin prolongation. In sections made more carefully, the thicker portion is seen to lie on the teeth of the first series, as shown in fig. 241, and the inner end appears directed towards the axis of the cochlea; but I will not answer for it, that the portion which is thus bent upwards is the true layer of this membrane, because, as I have said, it is so excessively difficult to see it *in situ*. If my figure should be incomplete in this respect, I should be inclined to believe that the thicker part of the striated lamella came externally into connexion with the lamina spiralis; but this point must be decided by future observations.—The striated lamella appears to be connective tissue. The thinner portion is marked with transverse striæ, and the thicker part is fibrous in a direction parallel to the long axis of the cochlea. One surface of the thicker portion often exhibits slight rib-like prominences, and at the rounded end there is often an appearance of a canal, in which I once thought I observed a blood-vessel. It is remarkable, that I never found, at this border of the membrane, any certain indication of an attachment to the other parts, while in the other direction the thin border always has the appearance of being torn away.— In the layer of connective tissue over the striated lamella, I believe that I have sometimes seen blood-vessels; but this layer may be very readily confounded with the loose shreds of periosteum of the scala vestibuli which have become turned over; and as these always contain vessels, I am not able to give any definite judgment on the point.

The *scala media*, in its situation and form is sufficiently indicated by fig. 241, and I will only add in this place, that it is certainly not filled with cells, as *Claudius* believes, but contains a liquid, and exhibits a distinct epithelium in some places. These places are, 1, the sulcus spiralis, from the apex of the teeth of the first series, up to the commencement of the organ of *Corti*; here there is a simple pavement-epithelium particularly conspicuous in the bottom of the furrow; 2, the zona pectinata, from the line of ending of the Cortian fibres onwards. It is very possible, that beyond these places, there are others which are covered with epithelium, and in one case especially, I have seen such a covering on the inner Cortian fibres, appearing to be a continuation of that on the sulcus spiralis; but on account of the

Fig. 246.

Perpendicular section through part of the lamina spiralis. From the second turn of the cochlea of an ox; treated with diluted hydrochloric acid; mag. 180 times. The organ of *Corti* is lettered as in the preceding preparations. *a.* periosteum and softened layer of bone on the aspect of the zona ossea, towards the scala vestibuli; *b.* habenula sulcata (*Corti*) with a capillary loop; *c.* teeth of the first series; *d.* sulcus spiralis lined with epithelium; *e.* habenula perforata (*mihi*); *f.* foramina through which the nerves pass from the scala tympani into the scala vestibuli; *g.* bipolar cells at the commencement of a Cortian fibre; *h.* posterior, and *k.* anterior segment of the Cortian fibre; *i.* pedunculated nerve-cells; *l.* nerve within the zona ossea; *m.* end of its dark-bordered fibres; *n.* lower tympanic periosteal lamella; *o.* lamina spiralis membranacea; *p.* lig. spirale; *q.* thin part of membrana Cortii.

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the lower surface of the commencement of the *habenula denticulata;* on the third half turn, lastly, they form a nervous border, 0·08‴ to 0·09‴ in breadth, which also lies on the lower side of the *habenula sulcata*. At the last two places however, the nerves are not contained free in the scala tympani, but are covered by the periosteum of the lower surface of the zona ossea. The nerve-tubes attenuated to 0·001‴, are described by *Corti* and others as terminating by becoming suddenly pale, finer, and then ending by free extremities. I have, however, recently found that all the nerve-tubes pass in a pale and attenuated condition through the apertures in the *habenula perforata,* and here, as stated above, become connected with the organ of *Corti*, in a manner which is not yet altogether clear. I was formerly of opinion that the nerve-fibres were united directly and singly with the inner Cortian fibres, but my more recent observations have rendered me very wavering in this belief. It is true that I have distinctly noticed the inner Cortian fibres seated upon the nervous tubes, but, on the other hand, I think I have also convinced myself that fibres of the cochlear nerve, after passing through the foramina in the habenula perforata, make their appearance beneath the teeth of the first series, in their direct course to small spindle-shaped and stellate cells, from the other end of which similar nervous fibrils are then given off. It may be supposed that these fibrils unite themselves with the pedunculated cells of the organ of *Corti,* but I can at present adduce no direct proof of such a connection. These processes extend so far, that I no longer venture to regard the other parts of the organ of *Corti* as being decidedly nervous in character; at the same time, I must continue to oppose the views of those who regard this structure as being simply of the nature of the basilar membrane.

The *vessels* of the cochlea, though fine, are yet very numerous, and are distributed, firstly, in the periosteum of the walls of the canal of the cochlea, and, secondly, in the lamina spiralis. At the former place, besides the capillary networks occurring everywhere, they form a special vascular stripe on the scala vestibuli, immediately over the ligamentum spirale, the *stria vascularis* (*Corti*): although connected with the vessels of the periosteum, the vessels of this stria lie above that membrane, and are imbedded, as it were, in the epithelium, along with a little pigment. In the *zona spiralis* there exists a rich capillary network, both in the osseous part and in the nervous expansion itself; it is connected with a *vas spirale* running on the lower or tympanic surface

of the zona membranacea, in the entire extent
vessel, which is probably venous, always lies b
denticulata, sometimes more internally, sometin
in the last half turn of the cochlea it is a ca
in diameter; towards the base, however, i
0·013‴ in breadth, and is distinctly compose
rare cases, there are two capillary vasa spira
mentioned, and *Corti* has twice found in ma
an outer *vas spirale* also, near the ligamentum
pectinata, but this did not communicate wit
the zona pectinata in general being non-vascul

We have still at the close to notice the a
nerve-tubes of its trunk measure in man 0·
extremely readily destructible, and possess or
lemma. Between the tubules, numerous gangl
in the trunk itself, and in the vestibular a
these cells are bipolar, apolar, or unipolar, pa
measure 0·02‴ to 0·07‴ in man and mammal
have only one pole, or none at all, are, pr
suggests, only mutilated bipolar ones, seein
nerve, especially in fishes, may possess bi
scarcely any others. Similar cells, but smal
as above mentioned, in the cochlea and on t
in the vestibule (*Pappenheim*, *Corti*). *Czerm*
fibres of the auditory nerve to divide in the
on the ampullæ and sacculus of the sturgeon;
have seen the same thing in the frog, and *Ley*

With regard to the development of the org
only be mentioned here, that, according to *I*
confirmed by *Reissner* and *Remak*, the mem
labyrinth are formed from the external skin b
version, so that they might be compared in
lens and the vitreous humour; in this proc
corresponding to the epidermis is chiefly co
exclusively, as *Remak* believes; and to the in
are superadded the auditory nerves from the b
ing structures, both hard and soft, from t
lamina, and thus the organ is completed. N
is known with regard to the histological dev
parts of the labyrinth.

For the *investigation* of the organ of hearing, whic
presents very considerable difficulties, perfectly fresh

pensably necessary, and are best got from animals quite newly killed; when it is desired to see the parts in a perfectly normal state, serum or a solution of sugar must be employed for moistening them; chromic acid preparations, too, are very proper for many purposes. Further, the successful examination depends upon a certain dexterity in exposing and detaching the delicate parts with which we have to deal; and much patience will be required, because it must frequently be left to accident whether a certain arrangement comes into view or not. In order to see the nervous plexuses of the zona ossea of the cochlea, this structure must be deprived of its calcareous salts by diluted hydrochloric acid, while, on the other hand, the ganglion-cells of this locality must be sought by careful breaking up of the osseous zone in a medium which has no chemical action on the parts. Perpendicular sections are important, and are to be obtained either from isolated laminæ spirales taken out of chromic acid preparations and treated with hydrochloric acid, or from whole cochleæ treated in this manner. Or we may lay the cochlea first in a bed of glue, and then make sections of the lamina spiralis.

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III.—OF THE ORGAN OF SMELL.

§ 235. The olfactory organ consists of the two *nasal cavities*, supported by bones and cartilages, and lined by a mucous membrane, and of a certain number of accessory cavities, viz., the *sinus frontales*, *sphenoidales*, *ethmoidales*, and the *antrum Highmori*. Of all these spaces, however, only the uppermost parts of the nasal cavities, where the olfactory nerve is distributed, are subservient to the sense of smell itself; for the other spaces are either simple conducting canals, concerned simultaneously in the function of respiration, or, at least, are destitute of any direct relation to the olfactory sense.

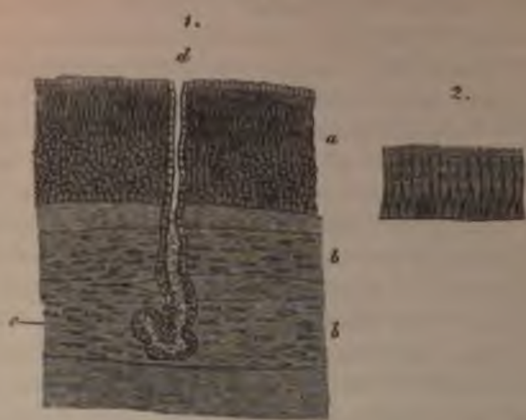
The above-mentioned hard structures do not present much worthy of remark; and of the bones it needs only to be mentioned, that in the ethmoid at its thinnest spots, the bony tissue consists only of a matrix and lacunæ, without Haversian canals. The cartilages of the nose are true cartilages, and bear most resemblance to that of the larynx, except that the contents of their cells are mostly pale and destitute of fat, the cell-walls but little thickened, and the matrix finely granular. Beneath the perichondrium of these cartilages there also lies a layer of flattened cells, which attains a thickness of 0·024‴ upon the septum; while in the interior the cells are more roundish, larger, and arranged in rows, in the direction of the thickness of the cartilaginous plate.

Of the coverings of these parts, we may first make mention of the external *skin* of the nose; this is characterised by a thin epidermis (0·024‴ to 0·032‴), a tense cutis, $\frac{1}{4}$‴ thick, with small undeveloped papillæ ($\frac{1}{40}$‴ to $\frac{1}{66}$‴), and fine hairs; and also by a dense adipose tissue, one line thick, intimately united with the cartilages, and containing large sebaceous glands extending into it, with small sudoriparous glands, $\frac{1}{10}$‴ to $\frac{1}{12}$‴. This external skin extends with its sebaceous glands, and provided with thicker hairs (vibrissæ), for some distance into the nasal cavity, almost up to the place where the external nasal cartilage ceases, and then passes imperceptibly into the mucous membrane of the olfactory organ; and this mucous membrane is continued from hence to form the lining of all the remaining spaces, though it does not present the same characters everywhere. According to *Todd* and *Bowman's* discoveries, which I can fully confirm, it is divided, in animals, into a ciliated and non-ciliated part, the latter of which is limited to the uppermost parts of the proper nasal cavities, where the olfactory nerve is distributed; this should, therefore, be called the *olfactory mucous membrane* in the stricter sense, while the other may retain the old name of *Schneiderian membrane*.

If we begin by inspecting the latter membrane — the ciliated portion of the nasal lining, we find that its structure is not everywhere the same; and we may conveniently distinguish the thicker glandular mucous membrane of the proper nasal cavity from the thinner one lining the accessory cavities, and the interior of the turbinate bones. In both places, the epithelium is of the lamellated ciliated kind, similar to that of the larynx (fig. 247, 2), measuring, in the sinuses, 0·018‴ to 0·020‴ in thickness, and in the proper cavity of the nose, as much as 0·042‴ in some places. It is composed, in man, of pale, finely granulated cells, of which the outermost ciliated ones measure up to 0·03‴; in animals, the cilia produce a current from before backwards. Then follows the proper substance of the mucous membrane, containing very few, if any, elastic elements, and chiefly composed of ordinary nucleiferous connective tissue, with numerous glands imbedded in it, in the portion which lines the proper nasal cavity. These glands are the ordinary racemose mucous glands, of various sizes, with gland-vesicles of 0·02‴ to 0·04‴ in diameter; and they are so thickly disposed in some places, particularly on the borders of the cartilages of the septum, and on the lower turbinate bones, that the mucous membrane in these spots acquires a thickness of one or even two lines. This thickness, however, is not attributable to the glands alone, but also to the presence of numerous, almost cavernous, plexuses of veins in the interior of the membrane (*Kohlrausch*, and myself); a sort of erectile tissue is thus produced, particularly in the mucous covering of the margin and hinder part of the lower turbinate bone. The glands are almost completely absent from the accessory cavities, and I have hitherto found them only occasionally in the antrum of *Highmore*; and here their excretory ducts and acini were sometimes dilated into muciferous cysts, which reached up to half a line in diameter. Except in this situation, the mucous membrane of the accessory cavities is extremely delicate, and is not separable from the periosteum as a special layer; in the nasal cavity itself, it may readily be peeled off, in spite of its intimate connection with the periosteum, especially at those spots where the glands are numerous. In pathological cases, the mucous covering of the sinuses, and of the turbinate bones in part, may exhibit calcareous deposits of various extent, so that the membrane acquires a white colour (myself, and VIRCHOW, *Entw. d. Schädelgr.*, p. 41).

The *proper olfactory mucous membrane* occupies only the uppermost parts of the septum nasi and of the lateral walls of the proper nasal cavities, in the situation of the uppermost turbinate bones. It extends downwards, therefore, from the *lamina cribrosa* for about three-quarters of an inch to an inch. Even to the naked eye, it is distinguished from the ciliated mucous membrane immediately adjoining it by its greater thickness and colour, being sometimes yellowish, as in man, the sheep, and calf; sometimes yellowish-brown, or brown, as in the rabbit and dog; and on microscopical examination, it is seen to be bounded by a pretty distinct dentated or undulating margin. The peculiarities of its structure are dependent on the nature of its epithelium, on the

Fig. 247.



From the nasal mucous membrane of the sheep; magnified 150 times. 1. Transverse section of the mucous membrane, from the proper olfactory region; *a.* epithelium without cilia; *b.* olfactory nerves, with a dividing pale nucleated bundle; *c.* gland of *Bowman*; *d.* aperture of the same. 2. Ciliated epithelium of the Schneiderian membrane.

occurrence of numerous glands of a peculiar nature, which I will call the 'glands of *Bowman*,' and, lastly, on the arrangement of the nerves. The epithelium is not at all ciliated in the lower animals, but in man cilia do exist in certain places, while in other spots they are wanting (*Ecker, M. Schultze*); it is also much thicker than the epithelium of the ciliated region, so that in the sheep, where the latter measures 0·03‴, the layer in question measures 0·05‴; and in the rabbit, they amount to 0·04‴ and 0·07‴ respectively. Notwithstanding this thickness, which is considerable for an epithelium, it is extremely delicate and soft, and can only be preserved, so as to show its separate elements distinctly, in certain particular solutions (*v. infra*). According to the more recent observations of *Eckhard*, and the still more valuable ones of *M. Schultze*, which have been confirmed in all respects by *Ecker* and myself, this epithelium has but one single layer of very long cells, between which are inserted other cellular structures, the apparent terminations of the olfactory nerve, or the olfactory cells (*M. Schultze*). The epithelial cells have exactly the structure of the elongated cells of ciliated epithelium, with this difference, that their filiform, irregularly defined, processes run down quite to the surface of the mucous membrane, and at their lower ends, divide into two or even more filaments, which may actually unite with those of neighbouring cells. The nuclei of these cells are oval, with a small distinct nucleolus and granular contents. The cells themselves, besides the ordinary granular matter, include in each a certain number of pigment-molecules, coloured yellow or brown, in various animals; on these the before-mentioned colour of the olfactory region mainly depends.—Much more difficult of investigation are the *olfactory cells*. These were correctly described by *M. Schultze* as long spindle-shaped structures, containing a round clear nucleus, with a distinct nucleolus and no pigment, and giving off from the opposite sides of the cell-body two fine filiform processes. The outer process is somewhat the thicker, passes between the broad portions of the epithelial cells to the external surface, and is here provided with a minute process, resembling a fine short hair, projecting beyond the epithelial cells. The inner process is a much more delicate filament, and can only be distinctly made out by a good microscope; in chromic acid preparations, it presents from place to place a number of small dark varicosities, which may occasionally be observed also on the outer filament. The olfactory cells appear to be arranged in a simple manner around each epithelial cell, and to form with their cell-bodies the greater portion of the middle and deeper strata of the epithelial layer, while their inner processes extend as far as the proper mucous membrane; it is a question whether they there become continuous with the fibres of the olfactory nerve.—In order to protect this epithelium, and to keep it moist, there are present in the whole of the proper olfactory region a large number of the glands of *Bowman*; a circumstance which is striking, as the portion of the ciliated mucous membrane immediately adjoining contains very few, or is even entirely destitute of glands. The glands of *Bowman* are simple cylinders, 0·08‴ to 0·1‴ long, either straight or slightly convoluted at the lower end; or else they have the form of extended pyriform tubes, which lie in crowded rows, chiefly between the larger branches of the olfactory

Fig 248.

1. From the frog; *a.* epithelial cells of the *regio olfactoria*; *b.* olfactory cells. 2. Small branch of the olfactory nerve of the frog, separating at one end into a brush of varicose fibrils. 3. Olfactory cell of the sheep. Magnified 350 times.

nerves; but in part also they are found more isolated, as at the lower limit of the olfactory region, and here bear most resemblance to certain forms of the glands of *Lieberkühn*, and of the embryonic sudoriparous glands. I have not perceived any divisions on the tubes, yet it is very possible that I have overlooked them, since these organs also are very delicate and easily altered. Their canals measure 0·014‴ to 0·025‴ in diameter, and are lined by a beautiful simple epithelium, of roundish polygonal cells, 0·006‴ to 0·008‴ in size; in these are contained more or less yellowish or brownish pigment-granules, which also assist in producing the various colours of the olfactory mucous membrane. The excretory ducts of the glands of *Bowman* are somewhat narrower (0·008‴ to 0·012‴) than the ducts within the glands, and are always lined by large roundish cells; they pass directly through the epithelium, and terminate on its surface by roundish apertures, which measure 0·01‴, and are surrounded by a few large cells (in the rabbit, I find here an elongated form of cells, and *M. Schultze* has observed similar ones in the sheep).—In man, these glands are represented by ordinary mucous glands; and besides these, the mucous membrane is composed here, as in its other regions, of a soft connective tissue, without elastic elements.

The vessels of the nasal mucous membrane are abundant in the proper nasal cavity, less numerous in the accessory cavities: their terminal branches are arranged partly in the form of loose plexuses around the glands, and in the trunks and branches of the olfactory nerves; partly in the form of a very dense network, on the surface of the mucous membrane itself. In the latter situation the vessels form numerous loops, somewhat horizontally disposed, and, at first sight, these loops suggest the existence of papillæ, although no such structures are present. The branches of the arteries and veins also anastomose in a variety of ways, and the latter form the rich cavernous plexus mentioned above, particularly on the lower turbinate bone. Nothing is known of the *lymphatics* of the nasal mucous membrane.—The *nerves* are, in the first place, branches of the fifth pair (*ethmoidales, nasales posteriores*, and a branch of the *dentalis anterior major*); and these are distributed especially to the ciliated region of the olfactory organ, and present the same conditions here as in other sensitive mucous membranes, that of the pharynx, for example. Fibres of these nerves also ascend into the proper olfactory region, and, as I have seen in one case in the calf, a few dark-bordered primitive tubes may even run from them in the course of branches of the olfactory nerves. The *olfactory* nerve possesses, in its *tractus* and *bulbus*, dark-bordered tubes and nerve-cells, of which we have already spoken above (p. 236). On the other hand, the *nervi olfactorii*, in man and in mammalia, nowhere

Fig. 249.

Olfactory tubes of the ox; magnified 350 times. 1. A thick grey tube; *a*. envelope of the same; *b*. effused contents with nuclei. 2. A fine dark-bordered tube, *a*. continuing from one of the foramina cribrosa into a pale nucleated fibre, *b*. 3. The empty envelope of a grey tube, at one of its extremities appearing collapsed and like a fibre.

contain any white medullated fibres, even in the main branches which arise from the bulbs, but consist throughout of pale, slightly granular, flat tubes, 0·002‴ to 0·003‴ in breadth, with elongated nuclei; these tubes are firmly connected and held together by envelopes of connective tissue running between them, and these are thicker and, consequently, whiter on the *rami ad septum*. The fibres of the olfactory nerve are very similar to the embryonic nervous elements, and a delicate, structureless envelope can be easily seen on them in animals, distinct from the finely-granular nucleated contents; towards their terminations, they are continued into finer and finer fibres, of 0·001‴ to 0·0005‴ in diameter, some of which may even be found in the trunks of the nerve. As for the origin of these nerve-fibres, nothing positive has yet been ascertained, either in man or in the lower mammalia; but from the observations of *Leydig* in the plagiostoma (*Beiträge*, p. 34, tab. i., fig. 6), and from other considerations, it is probable that they arise from the cells of the olfactory bulb; the details of their union with these cells, however, still remains to be investigated. The termination of the nerves is still more doubtful. This much is easily seen, that the olfactory nerves, in their course in the mucous membrane of the olfactory region, divide frequently at acute angles, become smaller and smaller as they descend, and produce a plexus. In mammalian animals, also, they can be traced over almost the whole of the proper olfactory region, but a little in front of the border of it their plexus is always withdrawn from view; nor can any trace of terminal twigs be met with, so that I remain quite in the dark with regard to the main question. However, according to the enquiries of *Schultze* in the frog, which I can confirm, it appears very probable that every olfactory fibre spreads out into a whole bundle of very fine, pale, varicose fibrillæ, which perforate the mucous membrane; and that each of these then unites itself with one of the olfactory cells.

In the investigation of the olfactory organ, the chief difficulty is presented by the delicacy of the epithelium, and, accordingly, a solution of albumen or the vitreous humor is alone to be used for moistening the parts. The process first recommended by *Eckhard*, and afterwards employed by *Schultze* with such happy results — the action of chromic acid and chromate of potash — has already been dwelt on. Perpendicular sections are best obtained with the scissors from detached pieces of the mucous membrane, and the borders of folds also frequently furnish good views. The mucous glands of *Bowman* are to be found on sections, or on teasing out the membrane, as well as on surface-views and perpendicular sections of hardened preparations. For the olfactory nerves, the most advisable method is to tease them out, and examine them with the addition of some vitreous humor or by chromic acid. To investigate the course of the nerve-trunks, chromic acid and caustic alkalies are of no service, but the compression of fresh preparations, or of such as have been moistened with soda or acetic acid, is rather to be recommended; for this purpose, too, the mucous membrane should be examined after long maceration in water, which leaves the nerves for a long time unaffected.

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ADDENDA ET CORRIGENDA.

Page 12, line 3, *for* Med., *read* Ned.
Page 56, heading of third paragraph *for* 1, *read* I.
Page 59, line 21, *for* § 16, *read* § 14.
Page 59, heading of second paragraph, *for* *k*, *read* II.
" " " " third " *for* *l*, *read* *a*.
" 60, " " first " *for* *m*, *read* *b*.

Page 143, *in* § 77, *insert the following*:— Some authors distinguish two kinds of sarcous elements in the muscular fibrillæ, the one dark and the other light. This view, adopted by *Dobie*, *Harting*, *Häckel*, *Rollett*, and others, has received strong confirmation from the observations of *Brücke*, that the darker elements are double-refracting. There can be no doubt, that, in many cases, dark and clear spots are seen regularly alternating in the course of a fibril, the darker portions only being the sarcous elements of *Bowman*; but this fact cannot be held to prove any essential difference of nature in the two portions which enter into the composition of a fibril. I regard the fibrillæ as consisting of one single kind of substance, everywhere equally contractile; and the dark and clear spots as being only thicker and thinner portions of this substance, formed in the process of contraction. This difference in density appears also to explain the unequal rapidity with which the two portions are affected by chemical agents, hydrochloric acid for instance.

Page 150, line 16, *for* rectinacula, *read* retinacula.

Page 178, *in* § 94, *insert the following*:—The soft centre of the intervertebral ligaments consists of cells, which are obviously derived from the cells of the chorda dorsalis of the embryo. In newly-born infants and in children, these cells are contained in a special pyriform cavity with a definite boundary.

Page 184, line 4, *for* and those of fossil animals, *read* and sometimes even those of fossil animals.

Page 275, *for the description of* Fig. 113, *substitute the following*, from *Todd* and *Bowman*:—

A. Vertical section, near the middle of the dorsal surface of the tongue; *a*, *a*. fungiform papillæ; *b*. filiform papillæ, with their hair-like processes; *c*. similar ones deprived of their epithelium; magnified two diameters. B. Filiform compound papillæ; a. ar secondary papillæ [which ought, however, to enter these pap d. secondary papillæ, deprived of e, e. the epithelium; f. ha the simple papillæ; magnified 25 diameters; g. separate nuc 300 diameters. 1, 2. Hairs found on the surface of the ton processes, showing varieties in the imbricated arrangement o of the particles towards the point; 5, encloses a soft hair; mag

Page 305, *in* § 141, *insert the follo* most recent observations of *Tomes* (*Mic* is shown to be extremely probable, tha by *Huxley* on the enamel of the growi than the outermost layer of the dev during the process of examination. Su be correct, we may regard the enamel a the cells of the *organon adamantinæ*, l many invertebrate animals, which stru cases formed of prisms, as I have elsewh

Page 406, line 26, *for* § 77, *read* §§ 7

Page 479, *at end of second paragr* p. 482).

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THE END.

[redacted]