THE

PHYSIOLOGICAL ANATOMY AND PHYSIOLOGY OF MAN.

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ADVERTISEMENT.

The following work is intended to furnish the Student and Practitioner in Medicine and Surgery with a plain and accurate view of the intimate structure and functions of the human body, and is accommodated, in its plan and arrangement, to the physiological lectures delivered in King's College, London. The authors have had a joint share in its composition, and are equally responsible for all it contains.

Incorporated in various parts of the work, the reader will find opinions expressed, relating both to the structure and functions of parts, more or less at variance with those generally received. To these the authors for the most part have been led during their anxious attempts to render their descriptions direct and faithful transcripts from nature.

Historical details, conflicting statements, and intricate discussions of doubtful physiological questions, have been almost wholly avoided, as being inconsistent with the end in view.

The authors desire to acknowledge their obligations to Mr. Vasey, the able and intelligent artist, by whom the engravings have been executed on wood.

They have likewise to express their regret at the delay which has occurred in the progress of their work. When the First Part was published in February, 1843, it was thought that the remainder might appear in two more Parts in the course of the following year. As their labours proceeded, however, it became necessary in some measure to modify the original plan, and to produce the work in two Volumes, of which the First is now complete. The remaining Volume will follow, in two Parts, at an early period.

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THE

PHYSIOLOGICAL ANATOMY

AND

PHYSIOLOGY OF MAN.

INTRODUCTION.

The aim of all natural knowledge is to ascertain the laws which control and regulate the phenomena of the universe. So numerous, and so diversified are these phenomena, that a division of labour has been found, not merely convenient, but absolutely necessary, for the study of them. The position and movements of the planetary system, the crust of the earth, and its various component strata, the treasures hidden in its womb, the abundant vegetation that grows upon its surface, or beneath its waters, and the numberless hosts of animals that dwell upon the land, or in the rivers, lakes, and seas, form separate branches of scientific investigation, between which a sufficiently distinct line of demarcation is established by the nature of the objects of inquiry peculiar to each. But, in all departments of science, the same general rules, for conducting the investigation, prevail, and it is only by a close adherence to these, that we can arrive at safe and satisfactory conclusions.

In any scientific inquiry, the first step must be, to form a general notion of the characters and properties of the objects of investigation. In the next place, it is necessary to observe carefully the phenomena which they naturally present; and, if they be within our reach, to produce such variation in them by artificial means (by experiments), as may serve to throw light upon them. If the phenomena, under observation, be complex, we must analyse them, with a view to ascertain the simpler ones, of which they are composed. By this analysis, and by the elimination of such as are merely collateral, we arrive at a phenomenon, uncomplicated, incapable of further subdivision, and fundamental; and this we are contented to receive as an *ultimate fact*, the result of a law in constant and universal operation. The accumulation of observations and experiments affords us Experience; points out the ordinary succession of phenomena, and teaches us the ways of Nature. If these phenomena are found to present a certain uniformity, we are authorized to refer them to the operation of one common Cause, and we are thus led to the expression of the Law which regulates their occurrence. Proceeding in this way, we are enabled to explain the whole train of phenomena which have been investigated,—that is, to devise a *Theory* which develops the rationale of their occurrence.

But sometimes our experiments and observations throw an imperfect light upon the phenomena which are the subjects of investigation; or the latter are so remote, or so little under our control, as to render both observation and experiment extremely difficult, and, in some cases, impossible. The "instances" which we are enabled to collect, are consequently dubious and obscure, and point darkly, or not at all, to ultimate facts; they present little or no general resemblance, and cannot be properly associated together. Here is no foundation on which to build a theory: but great advantage may be gained, if, with the little light we derive from these particular observations, aided by previous knowledge of general laws, we can frame a *hypothesis*, offering some explanation of the phenomena. The adoption of such an hypothesis, even for a temporary purpose, will "afford us motives for searching into analogies," may suggest new modes of observation and experiment, and "may serve as a scaffold for the erection of general laws."

Previously to the time of Lavoisier, chemists were perfectly familiar with the occurrence of combustion under various circumstances; but the opinions (hypotheses) which prevailed as to the real nature of this process, afforded a very unsatisfactory explanation of it. Subsequently, however, by the labours of Lavoisier, Davy, and others, this complex phenomenon has been observed in all its phases; it has been carefully analysed, and has been proved to occur in all cases, where substances possessed of strong chemical attractions, or different electrical relations, are brought within mutual influence. The *ultimate fact*, thus arrived at, is, that intense chemical combination always gives rise to the evolution of heat, and, in many instances, to that of light also.

Again, a great number of observations have shewn that bodies combine together only in certain quantities, or in multiples of them; that each body has its proper combining quantity, and that it never enters into combination except in that quantity, or some multiple of it. This is an *ultimate fact*, ascertained by numerous experiments, and indicates the law, which is so important in chemistry, that bodies unite with each other in their combining proportions only, or in multiples of them, and in no intermediate proportions. And this, again, has led to the beautiful generalization of Dalton, that the ultimate atoms of bodies are their respective combining quantities, and bear to each other the same proportion as their combining equivalents do.

Or, to take an example from the science which is to form the subject of the following pages. The function of respiration in animals is a very complex process, respecting the nature of which many unsatisfactory hypotheses had been formed, owing to the obscurity in which many of the phenomena, immediately or remotely connected with it, were involved. Until the law of the diffusion of gases, and of the permeability of membranes by them, had been developed, and until it had been shewn that carbonic acid is held in solution in venous blood, no theory of respiration could be framed adequate to explain all the phenomena. It is now proved, that, in this process, a true interchange of gases takes place through the coats of the pulmonary blood-vessels, the oxygen of the air abstracting and occupying the place of the carbonic acid of the blood. An admirable example is thus afforded of a most important vital process taking place in obedience to a purely physical law.

Living objects are those which properly belong to the science of Physiology. These are strongly contrasted with the inanimate bodies (which have never lived), to which other branches of natural science refer. At the same time, there are many points of resemblance between them; and as both owe their origin to the same Creative mandate, and are reducible (as will be seen by-and-by) to the same elementary constituents, so they are subject in a great degree to the same physical laws, and are to be investigated according to the same principles of philosophical inquiry.

We propose, in the first place, to compare living or organized bodies, with inanimate, mineral, or unorganized bodies, and to explain what is meant by the term Life. Secondly, to review briefly, and with reference to their leading distinctions, the phenomena of the vegetable and animal kingdoms. Thirdly, to point out the value of a knowledge of Physiology, especially that of Man, in relation to medicine, and to explain the best mode of pursuing it.

I. Every Living Being is *organized*,—that is, composed of different parts or *organs*, each of which has its definite structure, by which it differs from other parts, and is capable of fulfilling a certain end. The complex matter, which enters into the composition of an organized being, or *organism*, is termed *organic* matter, and is obtained by its proximate analysis. The ultimate analysis of this matter resolves it into elementary principles, such as constitute other objects of the universe.

The various bodies that compose the mineral kingdom, do not exhibit the same distinctness and variety of structure in their component parts, nor is there any adaptation of their parts to separate functions; they are therefore called *unorganized* or *inorganic*, and chemical analysis resolves them into those simple elements which admit of no further subdivision.

Organized bodies are found in two states or conditions. The one, that of *life*, is a state of action, or of capacity for action. The other, that of *death*, is one in which all vital action has ceased, and to which the disintegration of the organized body succeeds as a natural consequence.

An organized body in a state of *active* life exhibits certain processes, by which its growth and nutrition are provided for, and which enable it to resist the destructive influence of surrounding agents — processes, the object of which is to promote the development, and to preserve the integrity of the body itself. The simplest animal, or vegetable, is an illustration of this remark.

But there are organized bodies in which life may be said to be *dormant*. In these, no actions or processes can be observed, nor any change taking place: yet, if placed under certain favourable conditions, vital activity will soon become manifest. Of this, we have familiar examples in a seed, and in an egg. It is well known, that seeds will retain their form, size, and other properties for a very considerable period; and afterwards, if suitably circumstanced, will exhibit the process of germination as completely as if they had been only recently separated from the parent plant. Eggs, also, may be preserved for a long time without injury to the power of development, or to the nutrition, of the embryo contained within them.

It is worthy of observation, that those processes, which denote vital activity, may be sometimes temporarily suspended, even in fully formed animals and vegetables; and, in such instances, life may be said to *become dormant*. The privation of moisture is the ordinary cause of this interruption to the phenomena of life. In dry weather, mosses often become completely desiccated and appear quite dead, but will speedily revive on the application of moisture. And the common wheel animalcule, although apparently killed by the drying up of the fluid in which it had been immersed, will speedily resume its active movements on being supplied anew with water.

Inorganic bodies may be resolved by ultimate analysis into Oxygen, Hydrogen, Nitrogen, Carbon, and about fifty other substances, which Chemists regard as simple, because they appear to consist of one kind of matter only; that is to say, they have hitherto resisted further decomposition. These elements unite in certain definite proportions to form the compound inorganic substances. And this union may consist either of two simple elements — as oxygen and hydrogen, to form water; oxygen and the metal sodium, to form soda; chlorine and sodium, to form common salt; or, of one binary compound with another similar one, as of sulphuric acid (sulphur + oxygen) with soda (sodium + oxygen), to form sulphate of soda; or, again, of two such salts as the last with one another, as alum, which consists of sulphate of alumina united with sulphate of potassa.

As regards the mode of combination in the first of the examples enumerated in the preceding paragraph, where single equivalents of the elementary bodies unite, there can be but one opinion. In the formation of water, one equivalent of hydrogen combines directly with one equivalent of oxygen. But when one equivalent of one element is united with two or more of the other, to form the compound substance, the mode of combination is not so evident. Peroxide of hydrogen, for example, may either result from the direct combination of one equivalent of hydrogen with two of oxygen, or it may be a compound of one equivalent of water with one of oxygen.

In the second example, in which two binary compounds unite to form a salt, two modes of constitution have been suggested. The first supposes a direct union of a basic oxide with an acid oxide, as of soda (sodium + oxygen) with sulphuric acid (sulphur + oxygen) in sulphate of soda; and that each constituent preserves its proper nature in the compound. According to the second view, one of the constituents of the salt is supposed to undergo decomposition, yielding up to the other an element, which, joined to it, forms a compound radicle, to which the remaining element is united; as hydrogen would be to a simple, or compound radicle (chlorine or cyanogen), to form a hydro-acid. Thus, in the salt commonly called sulphate of soda, this view supposes that the soda yields its oxygen to the sulphuric acid, and that a compound is formed of sulphuric acid, plus an additional equivalent of oxygen, which may be represented by SO_4, and has been called by Professor Daniell oxysulphion. The compound radicle thus formed unites with the metal sodium, and the resultant salt should be called oxysulphion of sodium. This view, then, it is evident, would lead us to regard Glauber's salts as a binary compound, instead of a ternary one under the first theory; just as chloride of sodium is a binary compound, the compound radicle, oxysulphion, and the simple one, chlorine, standing in the same relation to the metal sodium.

This latter theory, of the binary constitution of salts hitherto regarded as oxygen salts, is of great interest in reference to the composition of organic substances, as will appear in a future paragraph. It has been supported by Professor Graham, and, subsequently, by Professor Daniell, whose opinion has been grounded on the phenomena of electrical decompositions.

Organized bodies are capable of being resolved, by chemical analysis, into the inorganic simple elements; but the list of simple substances which may be obtained from this source comprises only about seventeen.

Of the four widely-spread elements, oxygen, hydrogen, nitrogen, and carbon, two, *at least*, will be found in every organic compound; hence, as Dr. Prout has suggested, these four may be conveniently distinguished as the *essential* elements of organic matter. The other simple substances are found in smaller quantities, and are less extensively diffused; these may be termed its *incidental* elements. They are sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, silicon, aluminum, iron, manganese, iodine, and bromine; the last two are obtained almost exclusively from marine plants and animals.

Between these elementary substances, and the *organized* animal or vegetable texture, there intervenes a class of compounds, called *proximate principles*, or *organic compounds*, or *organizable substances*. These may be obtained in the first stage of the chemical analysis of various animal or vegetable tissues. From the organized structure, called *muscle*, for example, we obtain by analysis, first *fibrine*, a proximate principle, which is its chief constituent; and, subsequently, by the analysis of fibrine, we get the *simple elements*, oxygen, hydrogen, carbon, nitrogen, and sulphur, in certain proportions. On the other hand, by synthesis, the combination of certain inorganic elements (which hitherto has been effected only in the living body) will produce the organic compound, fibrine; from which, again, the organized structure, muscle, is formed. And so in other cases.

In the organized body the constituent particles are, as it were, artfully arranged, so as to form peculiar textures, destined to serve special purposes in the living mechanism of the animal or plant to which they belong. The organic compounds which may be obtained from these are devoid of this mechanical arrangement of particles, and it is a beautiful feature of the organized body, that every part has its special office, that there is nothing superfluous, nothing wanting. As each organized body has a certain end to serve in the œconomy of the living world, so each organ has its proper use in the animal or plant. In this adaptation of parts to the performance of certain functions, we see the strongest evidence of Design; and, amidst much apparent difference of form and obvious diversity of purpose, the anatomist recognizes a remarkable unity of plan — affording incontestable proof that the whole was devised by One Mind, infinite in wisdom, unlimited in resource.

The true proximate principles are those substances which are the first obtained by the analysis of the organized textures; such are *gluten, starch, lignine*, from the vegetable textures, or *albumen, fibrine, caseine,* from the animal ones. From these again a great variety of compounds has been obtained by various processes, owing to the tendency which their elements have to form new combinations. By boiling starch in dilute acids, it becomes converted into a kind of gum, and starch-sugar. By placing yeast in contact with sugar, the latter is converted into alcohol and carbonic acid, without the yeast affording it any of its chemical constituents; and, in the germination of barley, or of the potato, a peculiar substance is formed, the contact of which with the starch of the barley or potato converts it into sugar. Innumerable examples might be quoted from various vegetable compounds, shewing that the affinity, which holds together the elements of organic substances, is so feeble, that it affords but slight resistance to their entrance into new combinations. In this way a large class of organic matters is formed, which it seems proper to distinguish from the true proximate principles, under the name of *secondary organic compounds.*

In analysing the true proximate principles of organic substances, it is found that they consist for the most part of three or four of the essential simple elements, and that, as many of them contain a large number of atoms, their combining proportion is represented by a very high number. Respecting the mode of combination of these elements much uncertainty prevails. Some chemists consider them united equally with each other, and regard the organic principles themselves as ternary or quaternary compounds of them. But others have suggested a mode of combination more analogous to that of inorganic substances (see page 5); namely, that two or three of the elements form a compound radicle, with which the remaining one unites to form a binary compound. In a body, for example, consisting of three elements, two would form the compound radicle, or, in one composed of four elements, three would constitute it. This mode of composition has been rendered more probable in the secondary organic products than in the true proximate principles; and it may be illustrated by an example taken from the former class. Ether is composed of four atoms of carbon, five atoms of hydrogen, and one atom of oxygen; the carbon and hydrogen constitute a hypothetical compound radicle, called ethyl, which is united with one atom of oxygen: so that ether is an oxide of ethyl, and its formula may be expressed $C_4H_5 + O$.

Among the secondary organic products of the vegetable class we meet a few instances of binary compounds of simple elements; but the great majority of proximate organic elements, whether primary or secondary, are composed of three or four essential elements.

In contrasting, then, the chemical composition of organic with that of inorganic substances, we perceive, that, applying the binary theory to both classes of substances, their mode of combination is strictly analogous; there being, however, this distinction, that among organic substances combination with a compound radicle is the prevailing mode, and that the union of two simple substances is rare. If, on the other hand, we adopt the theory of oxy-acid-salts for inorganic compounds, and view the organic principles as ternary or quaternary compounds of simple elements, each to each, then it is evident that the most marked difference must exist between the two classes of compounds, the latter being formed on principles entirely dissimilar from those which regulate the composition of the former.

It is probable, however, that the progress of Chemistry will shew that the binary theory is applicable to both classes of substances, and that the same mode of chemical composition prevails through both kingdoms of Nature.

If so much uncertainty exists in reference to the manner of combination of the simple elements to form organic compounds, it is no wonder that the attempts of chemists to produce them by artificial processes should have met with so little success. No one has succeeded in the synthesis of any of the true proximate principles; and, indeed, it is very questionable whether any of those products of a vital chemistry will ever be produced elsewhere, than in the living organism. The formation of urea, a secondary organic compound, has been effected by Wöhler from the cyanate of ammonia, by depriving it of a little ammonia through the action of heat. And it must be admitted, as no unimportant step in the synthesis of organic compounds, that nitrogen gas has been found to unite with charcoal, under the influence of carbonate of potassa at a red heat. The cyanide of potassium, which is thus formed, yields ammonia, when decomposed by water; so that cyanogen, and, through cyanogen, ammonia, can be primarily derived from their respective elements contained in the inorganic world.* Allantoin, an analogous compound to urea, and formic acid, have likewise been artificially produced.

We proceed from this review of the chemical constitution of organic and inorganic substances, to compare them together in other respects.

In examining an organic substance which is *organised*, i. e. so constructed as to form part of a living organism, we find it to possess very distinctive characters. It generally contains water in considerable proportion; its form is more or less rounded and free from angularity, and it is never crystallized. When considerable hardness or density is required, the quantity of water is small, and an inorganic material is combined with the organic matter; as, in bones, phosphate of lime with the gelatine of the bone, or, in plants, silex with their epidermic tissues.

An organized body is composed of parts, distinct from each other in structure and function, and it may be subdivided into a series of textures, each differing from the others in physical and vital properties. The existence of a great variety of textures, in an animal, is an indication of a high degree of organization. Among the lowest organized creatures there is much uniformity of structure, although variety of parts or organs. Still these creatures by their actions shew that materials of different properties must exist throughout their bodies.

Fig. 1.

Primary organic cell, shewing the cell-membrane, the nucleus, and the nucleolus.

The simplest and most elementary organic form, with which we are acquainted, is that of a cell (Fig. 1), containing another within it (*nucleus*), which again contains a granular body (*nucleolus*).

* Graham's Chemistry, p. 709.

This appears, from the interesting researches of Schleiden and Schwann, to be the primary form which organic matter takes when it passes from the condition of a proximate principle, to that of an organized structure.

The bodies of some animals and of some plants, are composed almost entirely of cells of this kind; and in the early development of the embryo, all the tissues, however dissimilar from each other, consist at first of nucleated cells, which are afterwards metamorphosed into the proper elements of the adult texture.

An organized body possesses a definite form and disposition, not only as regards its component parts, but likewise when viewed as a whole. Each organized body has its appropriate and specific shape; and to each a certain size is assigned. To observe and classify the wonderful diversity of form exhibited by plants and animals, has given employment to Naturalists in all ages; and the sciences of Zoology and systematic Botany have been founded upon the results of their labours.

Every organized body is limited in its duration; it has "its time to be born and its time to die," and at death it passes by decomposition into simpler and more stable combinations of the inorganic elements.

In their origin, organized bodies are generally, if not always, derived from similar ones. Some have supposed that out of decaying vegetable or animal matter minute animals or plants of other kinds may be formed: but it seems most probable that in those cases in which they had been supposed to be formed, the seeds or eggs, or even the parents themselves, had been concealed in the decaying matter, or floated in the surrounding atmosphere. Recent experiments throw considerable doubt upon this doctrine of the *spontaneous generation* of organized bodies, by shewing that neither vegetation nor the development of animalculæ will go on in fluids which have been subjected to such processes as must inevitably kill whatever germs may have been diffused around or throughout them. In the present state of our knowledge it may be said, that the Harveian maxim, "Omne vivum ex ovo," is the rule; and that if there be any other mode in which the development of living beings takes place, it is the exception. The progress of Anatomical knowledge is every day revealing to us the organs, and the mode of generation in the minutest and the least conspicuous forms of vegetable and animal life; and thus the doctrine, which supposes that living objects may arise by a sort of conjunction of the elements of decomposing organic matter, becomes more and more improbable.

How beautiful is the provision which this power, possessed by organized bodies, of generating others, affords, for preserving a perpetual succession of living beings over the globe! The command, "Increase and multiply," has never ceased to be fulfilled from the moment it was uttered. Every hour, nay, every minute, brings into being countless myriads of plants and animals, to supply in lavish profusion the havoc which death is continually making; and it is impossible to suppose that the earth can cease to be in this way replenished, until the same Almighty Power, that gave the command, shall see fit to oppose some obstacle to its fulfilment.

In addition to this power of propagation, organized bodies enjoy one of conservation and reproduction. Solutions of continuity, the loss of particular textures, whether resulting from injury or from disease, can be repaired. Parts, that have been removed, may be restored by a process of growth in the plant or animal, and in some animals the reproductive power is so energetic, that if an individual be divided, each segment will become a perfect being. This power of reproduction is greater, the more simple the structure of the organized body; the more similar to each other are the constituent parts, the more easy will reproduction be. Numerous examples of this power may be adduced,— the healing of wounds, the adhesion of divided parts are familiar to every one. New individuals are developed from the cutting of plants: the division of the hydra into two, gives rise to the production of two new individuals. If a Planaria be cut into eight or ten parts, according to Dugès, each part will assume an independent existence.

The power of reproducing single parts only, is possessed by animals higher in the scale. In snails, part of the head, with the antennæ, may be reproduced, provided the section have been made so as not to injure the cerebral ganglion. Crabs and lobsters can regenerate their claws, when the separation has taken place at an articulation; and spiders enjoy the same power. In lizards, the tail, or a limb, can be restored, and in salamanders the same phenomenon has been frequently witnessed.

Organized bodies can appropriate and assimilate to their own textures other substances, whether inorganic or organic. This process is that which is most characteristic of living creatures: in virtue of it, animals and plants are continually adding to their textures new matter, by which they are nourished. Plants appropriate their nutriment from the inorganic kingdom, as well as from decaying organic matter; animals, chiefly from organic matters, whether animal or vegetable. Both possess the wonderful power of rearranging the constituents of these substances into forms identical with those of the elements of their various tissues —and of thus making them part and parcel of themselves.

Together with a process of supply, there is one of waste continually in operation. Animals and plants are ever throwing off effete particles from their organisms. These, under the name of *excretions,* appear in various forms—either as inorganic compounds, or as secondary organic products. Thus carbonic acid is given off in large quantities from animals; water, likewise, forms a considerable portion of their excreted matter, and serves to hold in solution salts, and secondary organic compounds, which result from the waste of the tissues. In this way, also, urea, lithic acid, and biliary matters are excreted. In plants, water is excreted from the leaves, a phenomenon which has been compared to the perspiration of animals; and various other excretions, which are sometimes made to serve an additional purpose in the œconomy of the vegetable, besides that of getting rid of superfluous matter, are doubtless formed by the secondary combinations of the effete particles of their textures.

These two processes, *excretion,* or the expulsion of effete particles, and *assimilation* of substances from without, are necessarily mutually dependent. As long as new matter is being appropriated, old particles must be thrown off, otherwise growth would be unlimited—and were excretion alone to go on, the destruction of the organism must speedily ensue, by the gradual waste of the tissues, to which no new supply was afforded. In both processes new combinations are taking place, as it were, in opposite directions; in the one from the simple to the complex to form organized parts, in the other, from the complex constituents of the textures to the simple organic, or inorganic compounds.

As each texture of the organism has this tendency to change during life, so, the whole organism tends to decomposition, when death puts a stop to all further absorption of nutritive matters. Dead organized matter is speedily dissipated under certain conditions. These are the presence of air, moisture, and a certain temperature, or contact with an organic substance which is itself undergoing decomposition. The affinity which held together the elements of the organic substances is destroyed by the cause which occasioned their death, and they are set free to obey new affinities and form new compounds.

When we consider the large number of equivalents which enter into the formation of each molecule of organic compounds, it need not excite surprise that a great variety of products results from the decomposition of animal and vegetable matter. This decomposition is of two kinds, which are distinguished by the names, *fermentation*, and *putrefaction*. Liebig proposes to limit the former term to the decomposition of substances devoid of nitrogen, and the latter to that of azotised matters. The products of vegetable matter in fermentation, by the action of yeast, are carbonic acid and alcohol; those of azotised matters, whether animal or vegetable, are carbonic acid, hydrogen, phosphuretted and carburetted hydrogen, hydrosulphuric acid, cyanogen, hydrocyanic acid, ammonia, and lactic acid.

Let us compare the characters of organized bodies, as described in the preceding paragraphs, with those of inorganic substances.

In form, in size, in duration, the contrast is most striking. The inorganic matters are aëriform, liquid, or solid: they are prone to assume the crystalline form, and to exhibit surfaces bounded by right lines, and uniting to form angles. No distinction of parts, or organs, is to be found in the mineral substance; its minutest fragment is in every respect of the same nature with the largest mass. A portion of chalk, not weighing a drachm, contains particles of the same form and size as those of the largest cliff on the sea-coast. Inorganic substances, as compared with organic, are unlimited in size and duration: they will continue for ages without augmentation or waste, provided no mechanical violence nor chemical agent be brought to act upon them.

None of those internal actions or processes, which we described in the organized body, occur in the unorganized one; there is no power of reproducing lost or injured parts, no growth, no excretion, no generation. From age to age the mineral remains unchanged, without motion, obedient to the common laws of matter, and unable to resist them by any inherent power.

Within the living organisms of the organic kingdom, on the contrary, are ceaseless motion and change. The absorption of the new material, and the ejection of the old, comprise a continual succession of actions, in which the organised being is ever *organizing* and *disorganizing*. This constant round of actions, which is the more diversified as the organism is more complex, we call LIFE. There is an apparent spontaneousness in these actions, which distinguishes the mechanism of an animal or plant from the machines of human construction. Yet the living organism is not the less dependent for the continuance, nay, for the very existence of those actions, upon the ordinary agencies of nature. Light, heat, the atmosphere, chemical affinity, each has its share in promoting the functions in the play of which Life consists; all are more or less necessary to the integrity of these actions; and it is contrary to experience to suppose that Life can be manifested without their co-operation. Yet we cannot say that Life is produced by, or is the result of, these agencies. It is equally contrary to experience to find the manifestation of Life in other than organized bodies. Nevertheless, it cannot be affirmed that organization is the cause of Life, for without the other agents no vital action occurs, and it has already been shewn that the organization of new matter is effected only by living bodies. The mutual co-operation of organized matter with the forces at work in the inorganic world, is necessary to the development of vital phenomena.

The term Life, then, may be regarded as denoting an ultimate fact in science, which may be thus expressed; that certain compounds of matter — which, as being artfully arranged in a particular form for a special end, and associated together by a certain mechanism, are called *organized* — do, by their co-operation with physical and chemical forces, manifest a train of phenomena, which are of the same, or of an analogous kind, for all organized beings; that is to say, they manifest the phenomena of Life. All organised substances, capable of thus co-operating with the other natural agencies, are called *living;* and, although they may not be positively in action, they are yet alive, as being ready to act when the complementary conditions to vital action shall be supplied to them. Thus the seed is alive, although not in action; but, immediately it is brought into contact with moisture and heat, life is manifested. Hence these agents, moisture, heat, light, &c. are said to act as *vital stimuli.* The organic matter, in becoming part of a living machine, acquires certain properties, very different from what it possessed before; these are called *vital properties*: they continue as long as the organization remains unchanged. For example, a certain proximate element is organized to form muscle; it then acquires the property of contractility, which it retains during life.

According to our experience, organic matter derives vital properties in by far the majority of instances, and probably in all, from a previously existing organism. The egg, while within the body of the mother, acquires vital properties; and it manifests an independent life when it is laid, if the requisite conditions (vital stimuli) are then supplied. Thus is life transmitted from one living being to another; and the life of a present generation of animals and plants has its source in that of a previous generation. If we trace a race upwards, through generations innumerable, to that which first flourished on the earth, we find the true source of vital action to be in Him, "in whom we live, and move, and have our being."

Thus, then, out of the same elements of which the inorganic kingdom consists, God has created a series of material substances, which by their action and reaction with other physical agencies, exhibit, apparently in a spontaneous manner, the phenomena of Life, and manifest a series of peculiar forces capable of opposing and controlling the other forces of nature. While these substances retain a perfect organization, and are supplied with their proper stimuli, vital actions go on without interruption, and no changes take place in the matter of the organism, excepting such as result from its proper affinities. But no sooner is the integrity of its structure destroyed, or the influence of the vital stimuli withdrawn, than action ceases, the organism *dies*, and the organic matter yields up its elements to form new compounds, a large proportion of which are inorganic.

Many are not content with this simple expression of facts, and seek a theory to explain the phenomena of organized bodies, and to account for the mysterious actions of Life. The ingenuity of philosophers has been not a little taxed for this purpose; and the history of the rise and fall of many a hypothesis, which has been framed upon this subject, affords a salutary warning to those who may be tempted to wander into the regions of speculation and fancy, deserting the safe and beaten path of inductive reasoning.

It does not fall within the scope of this work to examine the various theories of Life. One or two, however, we deem it right to notice, with the hope of at once exposing their inadequacy, and elucidating more fully the statement above given respecting Life.

From a very early period in the history of natural science, there has been a tendency to ascribe these effects to a certain principle, or Entity, possessing powers and properties which (however men may try to impress themselves with the contrary notion) entitle it to rank as an intelligent agent. It is true, that, according to most of the advocates of this doctrine, this power is supposed to be superintended and controlled by the Deity himself, and, by this supposition, they have screened themselves against the accusation of attributing to a creature the powers of the Creator.

A little examination of this doctrine will shew that it has no pretensions to the title of a theory.

Aristotle attributed the organization of animals and vegetables, and the vital actions exhibited by them, to a series of *animating principles* (ψυχαι), differing according to the nature of the organized bodies constructed by them, and acting under the direction of the Supreme animating principle (φυσις). He supposes that each particular kind of organized body had its proper animating principle, or ψυχη, and that the variety of the former really depended upon certain original differences in the nature of the latter, so that every distinct species of animating principle would necessarily have its appropriate species of body.

Harvey, likewise, assumes the existence of an *animating principle*, by which every organism is moulded into shape, out of materials furnished by the parent, and which, pervading the substance, regulates the various functions of its corporeal residence. But, at a subsequent stage of his inquiries, in assigning the blood as the special seat of this principle, he advances another supposition totally at variance with his previous hypothesis; namely, that as, during the development of the chick in ovo, the blood is formed and is moved, before any vessel, or any organ of motion exists, so in it and from it originate, not only motion and pulsation but animal temperature, the vital spirit, and *even the principle of life itself.* So completely biassed were the views of this illustrious man, by his exaggerated notions respecting the nature and properties of the blood!

The celebrated John Hunter, who does not appear to have been acquainted with the views expressed by Harvey, revived a somewhat similar hypothesis: and it is curious that the same fact should have so attracted the attention of both as to have given the first impulse to their speculations. This fact was, that a prolific egg will remain sweet in a warm atmosphere, while an unfecundated one will putrefy. The views of Hunter have been received with very general favour by English physiologists.

Hunter ascribes the phenomena of life to a *materia vitæ*, diffused throughout the solids and the fluids of the body. This *materia vitæ* he considers to be "similar to the materials of the brain;" he distinguishes it from the brain by the title "*materia vitæ diffusa*," while he calls that organ "*materia vitæ coacervata*," and supposes that it communicates with the former through the nerves, the *chordæ internunciæ*. And Mr. Abernethy, in commenting upon these views, explains Mr. Hunter's *materia vitæ* to be a subtile substance, of a quickly and powerfully mobile nature, which is superadded to organization and pervades organized bodies; and this he regards as, at least, of a nature similar to electricity.

Müller advocates the presence of an "*organic force*," resident in the whole organism, on which the existence of each part depends, and which has the property of generating from organic matters the individual organs necessary to the whole. "This rational creative force is exerted in every animal strictly in accordance with what the nature of each requires; it exists already in the germ, and *creates* in it the essential parts of the future animal."

An hypothesis, not dissimilar to that last mentioned, is maintained by Dr. Prout, and, as appears to us, it has been pushed by him to the utmost limits which the most fanciful speculation would admit of. He supposes that a certain *organic agent* (or agents) exists, the intimate nature of which is unknown, but to which very extraordinary powers are ascribed. It is superior to those agents whose operations we witness in the inorganic world: it possesses the power of controlling and directing the operations of those inferior agents. "If," says Dr. Prout, "the existence of one such organic agent be admitted, the admission of the existence of others can scarcely be withheld; *for the existence of one only is quite inadequate to explain the infinite diversity among plants and animals*." "In all cases it must be considered an ultimate principle, endowed by the Creator with a faculty little short of intelligence, by means of which it is enabled to construct such a mechanism from natural elements, and by the aid of natural agencies, as to render it capable of taking further advantage of their properties, and of making them subservient to its use."

The hypothesis of Aristotle, Müller, and Prout, and the earlier of those proposed by Harvey, seem all alike; they assume that organization and life are directed and controlled by an Entity, or Power, "endowed with a faculty little short of intelligence," the ψυχη of Aristotle, the animating principle of Harvey, the organic force of Müller, and the organic agent of Prout. What the mechanism may be by which this entity acts, they do not determine; but it is evidently such as bears no analogy to any known natural agency. Its existence is independent of the organism, for it has directed both the organizing process and the living actions of the being. Whence then is it derived? According to Müller, from the parent, for it exists in the germ,—it derives its powers from the same source, and its pedigree may therefore be traced to the first created individual of each species of animal or plant. Are we to conclude, then, that organic agents generate organic agents, and transmit their powers to their offspring? Or must we assume, that, for each newly generated animal or plant, a special organic agent is deputed "to control and direct" its organization, development, and growth?

The modern advocates of this doctrine have been driven to its adoption, from the difficulty (or, as they conceive, the impossibility) of explaining the phenomena of organization and life on principles analogous to those on which the changes of inorganic matter may be accounted for: this difficulty consisting in the supposed existence of certain differences in the mode of combination of the elementary constituents of organic and inorganic compounds, seconded by the fact, of the synthesis of organic compounds having hitherto baffled the chemist's art. It has puzzled them to think that out of the same elementary and proximate principles, so infinite a variety of animals and plants could be formed; and Dr. Prout has been especially staggered by the fact, that carbon and water, which contribute so largely to the formation of various organisms, have never, although aided by heat, light, and electricity, when out of an organized body, *and left entirely to themselves,* been able to unite, either in virtue of their own properties or from accident, so as to form any plant or animal, however insignificant.

In the first place, let it be observed, that many of the phenomena of life may be accounted for on physical or chemical principles. The changes effected in the air and in the blood by respiration, the phenomena of absorption, and, in some degree, those of secretion, are the results of purely physical processes. It is in the highest degree probable that many of the actions of the nervous system are due to physical changes in the two kinds of nervous matter, substances of complex constitution and high equivalent number, and therefore prone to change. Stomach-digestion is now known to be a chemical solution; the generation of heat is due to the same chemical phenomenon as will give rise to it in the inorganic world; and electricity is also similarly developed within the body. How entirely dependent on physical changes are the senses of vision and hearing, and how completely are their organs adapted to the laws of light and sound? And, doubtless, a further insight into the nature of the various organic processes will reveal to us a closer analogy between the laws by which the two great kingdoms of nature are governed.

Nor is there so great a chasm between matters organic and inorganic, as to chemical composition, as some would have us believe. It has already been shewn that modern chemical research tends to prove a similarity as regards the mode of combination of the elements in both; and the labours of chemists have been crowned with success in forming some organic products by artificial means. —(See p. 9).

And let it not be forgotten that the living laboratory of the animal and plant is one well stored with means for analysis and synthesis: the continual introduction of new material gives full scope to the play of chemical affinity, and at every point the constant attendants of chemical action, heat and electricity, are developed. May it not reasonably be inferred that these agencies, which the chemist can so readily turn to account in his artificial processes, are not idle in the work of combination and decomposition in the living body? A great difference as to sensible qualities, in the various organic products, by no means implies great difference of chemical constitution, for it is well known that the addition or removal of a single atom of one of the ingredients of any compound is sufficient to produce a substance with totally new properties; and such is the complex nature of organic molecules, that the attraction between their component elements yields readily to disturbing causes.

But how shall we explain the strange process of organization, in the production of that infinite diversity of forms, that "insatiable variety of Nature," which is so conspicuous in the vegetable and animal kingdoms? Must we imagine the creation, in corresponding number and variety, of a duplicate order of beings, whose duty it shall be to preside over the development of each species, and to impress each with its peculiar characters? Or does it not seem more consistent with that grand simplicity, which the phenomena of nature everywhere present, to suppose that the organization of animals and plants, in such great variety, is the result of the primary endowment of organic matter, at the creation of the first parents of each species, by the Almighty? The animal or vegetable matter of each species was created to propagate after a certain fashion, and after that only; the organic cells, of which these organisms consist in the early stages of development, have the power of evolving the adult tissues of animals and plants of their own species only; the simple volvox develops, from its interior, organic cells which become volvoces; and the cell which forms the ovum of the elephant or the mouse, is able, by an inherent power of multiplication, to evolve the skeletons and organs of each of those animals respectively.

The peculiar endowments of the organic matter, composing the various tribes of animals and plants, are transmitted from parent to offspring. But they admit of certain modifications under the influence of circumstances affecting the parents, as is proved both in the animal and vegetable kingdoms in the production of hybrids. "Two distinct species of the same genus of plants," says Dr. Lindley, "will often together produce an offspring intermediate in character between themselves, and capable of performing all its vital functions as perfectly as either parent, with the exception of its being unequal to perpetuating itself permanently by seed; should it not be absolutely sterile, it will become so after a few generations. It may, however, be rendered fertile by the application of the pollen of either of its parents; in which case its offspring assumes the character of the parent by which the pollen was supplied." The same thing precisely occurs among animals, and the mixed offspring, or mule, produced by the union of different species, is incapable of breeding with another mule; but not so with an animal of the same species as either of its parents. How entirely inadequate is the theory of organic agents to explain these occurrences; it cannot, surely, be maintained that a mixed organic agent is produced from the conjunction of the organic agents of the dissimilar species to direct the formation of this mixed organism!

The remarkable fact, that the various tribes of the human race, dissimilar as they are, were derived from the first created pair, may be adduced as a striking illustration of the influence of physical agency in modifying organic development. The most potent cause of these changes has been climate; but particular customs and usages, connected with the uncivilized state, have not been without their influence. Climate also produces considerable modifications in the size and other characters of the lower animals. Sturm affirms that cattle transported from the temperate zones of Europe (Holland or England), to the East Indies, become considerably smaller in their succeeding generations.

The theory of organic agents affords no more satisfactory explanation of disease, or of death. In both cases the organic agent must be at fault; for as it is the sole guide and controller of the organizing process, so it is not to be supposed that anything can go astray, except under its guidance. And yet it seems impossible to imagine that the ordinary causes of disease could affect such an entity. On the other hand, any physical or mental cause, general or local, affecting the substance of which the body is composed, may so alter and modify the affinities of its particles as to occasion a material disturbance in their actions; and it is not difficult to conceive that this disturbance may be of such a kind as to put a stop to vital action immediately or remotely.

So much for the dependence of Life and Organization on a controlling and directing Entity. The sagacity of John Hunter led him to reject this doctrine entirely; but, as he completely passed over the influence of the natural agencies of inorganic nature upon organized beings, he was forced to assume the presence of a peculiar material substance, pervading and giving vital properties to solids and fluids: yet such a constituent of the body ought to be demonstrable by chemical or other means. It is clear that this *materia vitæ* cannot be, as Mr. Abernethy suggested, electricity, or anything akin to it. Electricity requires for its development the reciprocal action of different kinds of matter, and it is abundantly evolved in various animal processes, as a necessary result of chemical laws. If, therefore, organization and vital actions depended upon electricity, this agent would, at once, be formed by, and direct the formation of, each organism.

Mere composition of matter does not give life, says Hunter; if he had added, that organized bodies acted on by, and co-operating with, certain vital stimuli developed vital actions, there would have been no need for the assumption of a *materia vitæ*. The resistance which living animals introduced into the stomach are capable of affording to its solvent powers, and the digestion of the walls of the stomach by its own fluid after sudden and violent death, seemed to denote that the dead animal, or dead stomach, had lost a something which previously protected them against the influence of the gastric fluid. But this is no more than a case familiar to chemists, viz. the influence of a stronger affinity controlling a weaker. When iodide of potassium is mixed with a solution of starch, no change ensues; but, if a minute quantity of chlorine be added, a blue iodide of starch is instantly formed: the superior affinity of the iodine for the potassium hindered the union of the former with the starch; but, as soon as the iodine was set free by the stronger attraction between the potassium and the chlorine, it speedily united with the starch. So, in the living animal, the affinity of its component particles for each other is greater than their affinity for the gastric fluid; but in the dead animal the former affinity is destroyed, the latter comes into play. Whether is it more philosophical to assume the removal of a particular agent, for which removal no cause can be assigned; or, to state the simple fact of the physical difference between dead and living organic matter?

II. It is very difficult to define a precise boundary between the vegetable and animal kingdoms. The lowest animals exhibit so much of the plant-nature, that naturalists are as yet undecided as to the true location of some species. The common sponge, for instance, is claimed for each kingdom.

The various processes by which are effected the ceaseless motion and change, so characteristic of living beings, are called, in physiological language, *Functions.*

The functions, which are common to all organized beings, have a two-fold object: the preservation of the individual, and the propagation of the species. Those destined for the former purpose are the *Nutritive Functions:* those for the latter are comprehended under the general title *Generation.*

The first step in the nutritive functions of both plants and animals, is to form a fluid, which contains all the elements necessary to nourish the various textures, and to supply materials for the secretions. This fluid is, in plants, *the sap ;* in animals, *the blood.*

In both classes of beings a process of *absorption* precedes the full developement of the nutritive fluid: it is by this means that material is obtained for its formation. Within the plant or animal it becomes more completely elaborated.

In plants, the absorption takes place by the spongioles of the roots. A fluid, already prepared in the soil, — water, holding in solution carbonic acid and various mineral substances, — passes through them into the vegetable organism, without undergoing any reduction or preparation during its transit. In animals, however, the food experiences much change, and a more or less elaborate process of *digestion* takes place, before a fluid is formed, capable, when absorbed, of furnishing the materials of the blood.

Plants, fixed by their roots in the soil, imbibe from it their nutriment. Animals, obtaining food from various sources, introduce it into a digestive cavity, where it is prepared for absorption.

The presence of a digestive organ, or stomach, is characteristic of animals. The only instances in which a similar organ may be supposed to exist in the vegetable kingdom, are to be found in those remarkable modifications of leaves, called pitchers (*ascidia*) in *Nepenthes, Sarracenia,* and *Dischidia.* In the last two plants, these organs certainly serve to retain and dissolve the bodies of insects in the fluid which partially fills them: in *Sarracenia,* according to Mr. Burnett, the fluid contained in the pitchers is very attractive to insects, which, having reached its surface, are prevented from returning by the direction of the long bristles that line the cavity. The dissolved food is then absorbed into the plant.

On the other hand, the animal kingdom affords some exceptions to the presence of a stomach. In such animals, the absorption of nutrient fluid takes place by a general surface. The *Volvox globator* has no inlet to its interior but through the pores in its walls. A parasite of the human body, the *Acephalocyst*, also derives its nutriment by imbibition through its walls. A familiar example is the *Acephalocystis endogena*, or pill-box hydatid of Hunter. It consists of a globular bag, closed at all points, containing a limpid fluid, capable of growth, and of reproduction by the development of gemmules from the inner surface of the sac. The *Echinococcus* is also nourished by direct absorption into the walls of the globular sac of which it consists.

Some difference may be noticed as regards the nature of the food in animals and plants. The former derive their nutriment entirely from the organized world, unless, indeed, we suppose that the nitrogen absorbed in respiration contributes to their sustenance. Plants appropriate inorganic elementary matters for food, as carbon, carbonic acid, ammonia, &c. "Inorganic matter," says Liebig, "affords food to plants; and they, on the other hand, yield the means of subsistence to animals. The conditions necessary for animal and vegetable nutrition are essentially different. An animal requires for its development, and for the sustenance of its vital functions, a certain class of substances which can only be generated by organic beings possessed of life. Although many animals are entirely carnivorous, yet their primary nutriment must be derived from plants; for the animals upon which they subsist receive their nourishment from vegetable matter. But plants find new nutritive material only in inorganic substances. Hence one great end of vegetable life is to generate matter adapted for the nutrition of animals out of inorganic substances which are not fitted for this purpose."

The nutrient fluid, however formed, is distributed throughout the textures of the plant, or animal, by vital or physical forces, or by the junction of both; and the function, by which this is effected, is called *Circulation*. In plants, this function is very simple, and is performed without the agency of a propelling organ; but, in the greatest number of animals, such an organ, a *heart*, is the main instrument in the distribution of the blood. In animals, then, there is a true circulation; the fluid setting out from, and returning to, the same place. But, in plants, the fluid is found to circulate, or rotate, within the interior of cells, as in *Chara* and *Vallisneria*, the fluid of one cell not communicating with that of the adjacent ones, or to pass up from the spongioles in an ascending current, and to descend in another set of vessels.

But in many simple animals, some entozoa, for example, and polygastrica, there is no good evidence of the existence of any circulation at all; their textures imbibing the fluid in which they live.

The presence of atmospheric air is necessary to the existence of all organized beings. The air both passes by endosmose into their nutrient fluids, and receives from them certain deleterious gases developed in their interior. The function, by which the fluids are thus aërated, is called *Respiration.* In plants, the introduction of atmospheric air conveys nutriment to the organism; carbonic acid and ammonia are thus introduced; the former is decomposed, its carbon is assimilated, and its oxygen is exchanged for a fresh supply of atmospheric air. As the agent in the decomposition of the carbonic acid is light, it is evident that the generation and the evolution of oxygen can take place only in the day-time. Consequently, during the night, the carbonic acid, with which the fluids of the plant abound, ceases to be decomposed, and is exhaled by its leaves. Hence, plants exhale oxygen in the day-time, and carbonic acid at night.

In animals, carbonic acid accumulates in the blood during its circulation; and, when the atmosphere is brought to bear upon the capillary vessels containing the blood charged with this gas, a mixture takes place through the delicate walls of the vessels, the atmospheric air passing in, and carbonic acid, with nitrogen and oxygen, in certain proportions, escaping. Thus the evolution of carbonic acid, and the absorption of oxygen and nitrogen, are the characteristic features of respiration in animals.

It is highly interesting to notice, how plants are thus subservient to the well-being of animals, in the respiratory function, as well as in preparing nutriment for them. By their respiration they serve to purify the air for animals; for, in absorbing the carbonic acid from the atmosphere, they are continually depriving it of an element which, if suffered to accumulate beyond certain bounds, would prove destructive to animal life.

From the fluids of animals and plants, certain materials are separated by a singular process, nearly allied in its mechanism to nutrition, and called the function of *Secretion.* The secreted matters are various, and have very different ends: in some cases being destined for some ulterior purpose in the œconomy; in others, forming an excrement, the continuance of which in the organism would be prejudicial to it.

The function, which has for its object the propagation of the species, *Generation*, presents many points of resemblance in plants and animals. In the former it is cryptogamic, or phanerogamic; in the latter, non-sexual, or sexual. In the phanerogamic and sexual, the junction of two kinds of matter furnished by the parents is necessary to the development of fertile ova. In the cryptogamic and non-sexual generation, the new individual is developed by a separation of particles from the body of the parent, by which the new formation is nourished until it has been so far matured as to be capable of an independent existence.

The functions, hitherto enumerated, may be called *organic*, as being common to all organized beings; but there are others which, as being peculiar to, and characteristic of, animals, may be appropriately designated *animal* functions.

The prominent characteristic of animals is the enjoyment of *Volition* or *Will*, which implies necessarily the possession of *Consciousness*. Our knowledge of the share which consciousness and the will have in the production of certain phenomena of animal life, is derived from the experience which each person has of his own movements, and a comparison of them with the actions of inferior animals. We are conscious that, by a certain effort of the mind, we can excite our muscles to action; and when we see precisely similar acts performed by the lower creatures, with all the marks of a purpose, it is fair to infer that the same process takes place in them as in ourselves. Moreover, we learn by experience, that injury or disease of the nerves, which are distributed to our muscles, destroys the power of accomplishing a certain act, but does not affect the desire or the wish to perform it: and experiments tell us that the division of the nerves of a limb in a lower animal destroys its power over that member; while its ineffectual struggles to move the limb obviously indicate that the will itself is not affected by the bodily injury, though its powers are limited by it.

Again, certain external agents are capable of affecting the mind, through certain organs, thus giving rise to *Sensations*. Light, sound, odour, the sapid qualities of bodies, their various mechanical properties, hardness, softness, &c., are respectively capable of producing corresponding affections of the mind, which experience leads us to associate with their exciting causes, and which may be agreeable, and produce *pleasure*, or the reverse, and give rise to *pain*.

In a similar way to that by which we learn that the will stimulates our muscles through the nerves, we can ascertain that the nerves are the channels through which our sensations also are excited. "Certain states of our bodily organs are directly followed by certain states or affections of our mind; certain states or affections of our mind are directly followed by certain states of our bodily organs. The nerve of sight, for example, is affected in a certain manner; vision, which is an affection, or state of the mind, is its consequence. I will to move my hand; the hand obeys my will so rapidly, that the motion, though truly subsequent, seems almost to accompany my volition, rather than to follow it."*

And in all the inferior animals, possessed of like organs, there can be no doubt that sensations may be produced similar to those which arise in the human mind. In many of them, indeed, the sense of sight, hearing, or smell seems much more acute than in man, and affords examples of a beautiful and providential provision for the peculiar sphere which the creatures are destined to occupy. The unerring precision of the beast or bird of prey in pouncing upon its victim — the accuracy with which the hound tracks by its scent the object of its pursuit — or, the quickness with which most of our domestic animals detect sounds and judge of their direction, are familiar illustrations of the superiority of these senses in animals whose general organization is inferior to that of man.

There are few animals, however small and insignificant, in which we cannot recognize evidence of a controlling and directing will. But even in those few, in which voluntary movements are not distinctly to be discerned, the presence of a special system of organs, with which in the higher animals volition and sensation are associated, namely, a *nervous system*, serves as a characteristic distinction from plants.

A power of perception, and a power of volition, together constitute our simplest idea of *Mind;* the one excited through certain corporeal organs, the other acting on the body. Throughout the greatest part of the animal creation mental power exists, ranging from this its lowest degree — a state of the blindest instinct, prompting the animal to search for food — to the docility, sagacity, and memory of the brute; and to its highest state, the reasoning powers of man.

The phenomena of Mind, even in their simplest degree of development, are so distinct from anything which observation teaches us to be produced by material agency, that we are bound to refer them to a cause different from that to which we refer the phenomena of living bodies. Although associated with the body by some unknown connecting link, the mind works quite independently

* Dr. Brown. Philosophy of the Human Mind, p. 106.

of it; and, on the other hand, a large proportion of the bodily acts are independent of the mind. The immortal soul of man, *divinæ particula auræ*, is the seat of those thoughts and reasonings, hopes and fears, joys and sorrows, which, whether as springs of action or motions excited by passing events, must ever accompany him through the chequered scene in which he is destined to play his part during his earthly career.

Although the animals, inferior to man, exhibit many mental acts in common with him, they are devoid of all power of abstract reasoning. "Why is it," says Dr. Alison, "that the monkeys, who have been observed to assemble about the fires which savages have made in the forests, and been gratified by the warmth, have never been seen to gather sticks and rekindle them when expiring? Not, certainly, because they are incapable of understanding that the fire which warmed them formerly will do so again, but because they are incapable of abstracting and reflecting on that *quality* of wood, and that *relation* of wood to fires already existing, which must be comprehended, in order that the action of renewing the fire may be suggested by what is properly called an effort of reason."

Yet animals are guided by *Instinct* to the performance of certain acts which have reference to a determinate end: they construct various mechanical contrivances, and adopt measures of prudent foresight to provide for a season of want and difficulty. None of these acts could be effected by man without antecedent reasoning, experience, or instruction. But animals do them without previous assistance; and the young and inexperienced are as expert as those which have frequently repeated them. "An animal separated immediately after its birth from all communication with its kind, will yet perform every act peculiar to its species in the same manner, and with the same precision, as if it had regularly copied their example, and been instructed by their society. The animal is guided and governed by this principle alone, by this all its powers are limited, and to this all its actions are to be ultimately referred. An animal can discover nothing new; it can lose nothing old. The beaver constructs its habitation, the sparrow its nest, the bee its comb, neither better nor worse than they did five thousand years ago."

In plants there is no nervous system; there are no mental phenomena. The motions of plants correspond in some degree with those movements of animals in which neither consciousness nor nervous influence participate. Such movements are strictly organic, and result from physical changes produced directly in the part moved. Amongst the most interesting examples of these movements are those of the *Mimosa pudica*, the *Dionæa muscipula,* and the *Berberis.*

III. It is the province of Physiology to investigate the ways in which the functions of living beings are effected; and this investigation naturally involves the examination of their mechanism, of the chemical constitution, and of the properties of their component textures. The study of Anatomy must always accompany that of Physiology, on the principle that we must understand the construction of a machine before we can comprehend the way in which it works. The history of physiology shews that it made no advance until the progress of anatomical knowledge had unfolded the structure of the body. There is so much of obvious mechanical design in the intimate structure of the various textures and organs, that the discovery of that structure opens the most direct road to the determination of their uses. That kind of anatomy which investigates structure with a special view to function may be properly designated *Physiological Anatomy.*

A correct physiology must ever be the foundation of rational medicine. He who is ignorant of the proper construction of a watch, and of the nature of the materials of which it is made, could not find out in what part its actions were faulty, and would therefore be very unfit to be entrusted with repairing it. In medicine, the first step towards the cure of disease is to find out what the disease is, and where it is situated (*diagnosis*). Without a knowledge of the offices which various parts fulfil in the animal œconomy, our search to determine what organ or function is deranged must be most vague and indefinite. *Pathology* is the physiology of disease; and it is obvious, that no pathological doctrines can command confidence, which are not founded upon accurate views of the natural functions. It is also certain that improvements in pathology must follow in the wake of an advancing physiology.

The practice of medicine and surgery abounds with examples illustrating the immense benefits which physiology has conferred upon the healing art. The great advance which has been made of late years in the pathology of nervous diseases, is mainly owing to the discoveries of Bell, and many others, in the functions of various nerves, and the general doctrines of nervous actions. We may instance the case of the facial nerve — the portio dura of the seventh pair. It was supposed formerly that this nerve was the seat of that painful disease, called *tic douloureux,* and section of it has been performed for the relief of the patient. It is now known that this nerve could not be the seat of a very painful disease, for it is itself, in a very great degree, devoid of sensibility. It need hardly be added, that the operation is discarded.

The dangerous disease, to which many children have fallen victims, *laryngismus stridulus* or *crowing inspiration*, although admirably described by practical physicians, was never properly understood until the functions of the laryngeal nerves were clearly ascertained, and until it had been shown that spasmodic actions may be excited by irritation of a remote part, or through a stimulus reflected from the nervous centre. It is now known, that this disease has not its seat in the larynx, where those spasms occur which excite so much alarm for the fate of the little patient; but that it is an irritation of a distant part, which derives its nerves from the same region of the cerebro-spinal centres within the larynx,—that the afferent nerves of that part convey the irritation to the centre, whence it is reflected by certain efferent nerves to the muscles of the larynx.

The accurate diagnosis of diseases of the heart rests entirely upon a correct knowledge of the physiology of that organ. This improvement in medicine may be said to date from the time of Harvey, for he was the first who clearly expounded the mechanism of the central organ of the circulation. But the application of auscultation to the exploration of the sounds developed in its action, and the correct interpretation of those sounds in health by the experiments and observations of the last few years, have almost completely removed whatever difficulties stood in the way of the detection of cardiac maladies.

We are not less indebted to the illustrious Englishman, who discovered the circulation of the blood, for having paved the way to a rational treatment of aneurismal and wounded arteries by the modern operation of placing a ligature between the heart and the seat of the disease or injury. "The active mind of John Hunter," says Mr. Hodgson, "guided by a deep insight into the powers of the animal œconomy, substituted for a dangerous and unscientific operation, an improvement founded upon a knowledge of those laws which influence the circulating fluids and absorbent system; and few of his brilliant discoveries have contributed more essentially to the benefit of mankind."

In investigating the functions of the human body, the physiologist cannot do better than follow the instructions laid down by Haller in the preface to his invaluable work, "Elementa Physiologiæ Corporis Humani."

The first and most important step towards the attainment of physiological knowledge, is, the study of the fabric of the human body. "Et primùm," says Haller, "cognoscenda est fabrica corporis humani, cujus penè infinitæ partes sunt. Qui physiologiam ab anatome avellere studuerunt, ii certè mihi videntur, cum mathematicis posse comparari qui machinæ alicujus vires et functiones calculo exprimere suscipiunt, cujus neque rotas cognitas habent, neque tympana, neque mensuras, neque materiam."

A knowledge of human anatomy alone is, however, not sufficient to enable us to form accurate views of the functions of the various organs. Before an exact judgment can be formed of the functions of most parts of living bodies, Haller says, that the construction of the same part must be examined and compared in man, in various quadrupeds, in birds, in fishes, and even in insects. And, in proof of the value which attaches to this knowledge of *comparative anatomy,* he shews how, from that science, it may be determined that the liver is the organ which secretes bile; and that the bile found in the gall-bladder is not secreted by, but conveyed to, that organ: for no animal has a gall-bladder without a liver, although many have a liver without a gall-bladder; and, in every case where a gall-bladder is present, it has such a communication with the liver, that the bile secreted by the latter may be easily transferred to the former. "Vides adeò," he adds, "bilem hepate egere, in quo paretur, vesiculâ non egere, non ergo in vesiculâ nasci, ex hepate verò in vesiculam transire."

And Cuvier has happily compared the examination of the comparative anatomy of an organ, in its gradation from its most complex to its simplest state, to an experiment which consists in removing successive portions of the organ, with a view to determine its most essential and important part. In the animal series we see this experiment performed by the hand of nature, without those disturbances which mechanical violence must inevitably produce. We thus learn, from comparative anatomy, that the vestibule is the fundamental part of the organ of hearing; and that the other portions, the semicircular canals, the cochlea, the tympanum and its contents, are so many additions made successively to it, according as the increasing perceptive powers of the animals rendered a more delicate acoustic organ necessary. In a similar manner we learn, that one portion of the nervous system, in those animals in which it has a definite arrangement, is pre-eminently associated with the mental principle, and is connected with, and presides over, the other parts. This organ, the brain, is always situate at the anterior or cephalic extremity of the animal, and with it are immediately connected the organs of the senses, the inlets to perception. We soon find that the brain exhibits a subdivision into distinct parts; and of the relative importance of these parts, and their connexion with the organs of sense, and with the intellectual functions, we derive the most important information from the study of comparative anatomy.

Haller further assigns the examination of the living animal as a valuable aid in physiological research. Doubtless, many obscure points have been elucidated by experiments on living animals, and discoveries have been made which have greatly contributed to the progress of physiology; but the best physiologists are ever reluctant to interrogate nature in this way, knowing that replies elicited by torture are rarely to be depended upon. Very useful knowledge may be derived from observing the play of certain functions in living animals, or in Man himself,—contrasting them in various individuals, and noting the effects of age, sex, and temperament, and ascertaining the influence which other conditions, natural or artificial, may exert upon them.

The investigation of disease, both during life and after death, is of great value to enable us to appreciate the action of an organ in health. If, for example, as Haller remarks, a particular function be ascribed to a certain part, how can there be a more favourable opportunity of testing the accuracy of such a doctrine than by the examination of a body in which that part was affected with a disease, of which the previous history was known? If the function in question had been vitiated, or destroyed, it may be fairly presumed to have had its seat in the diseased organ. Nothing has contributed more largely to determine the functions of particular nerves, than exact histories of the symptoms during life, in cases in which they had been found, after death, in a diseased condition.

For exploring the minute structure of various textures, the anatomical elements of the body, Haller advises the use of the *Microscope.* The great improvements which modern opticians have accomplished, not only in the dioptric but also in the mechanical adjustments of this instrument, render it an invaluable adjuvant in physiological research. We shall have frequent occasion in the following pages to refer to anatomical analyses, effected by the microscope, of the utmost value to the knowledge of function. It may, however, be remarked, that, as the sources of fallacy are numerous even with the best instruments, more depends upon the observer himself, in this kind of investigation, than in almost any other.

The great impediment to deriving correct inferences from microscopical observations has arisen from the discordance, too apparent, in the narrations of different observers. This discordance has been the result of a twofold cause; namely, imperfection of the instruments, and the very unequal qualifications of different observers. The former cause is now almost completely removed; the latter must remain, while men imperfectly appreciate their own abilities for particular pursuits.

To make microscopical observation really beneficial to physiological science, it should be done by those who possess two requisites: an *eye*, which practice has rendered familiar with genuine appearances as contrasted with those produced by the various aberrations to which the rays of light are liable in their passage through highly refracting media, and which can quickly distinguish the fallacious from the real form; and a *mind*, capable of detecting sources of fallacy, and of understanding the changes which manipulation, chemical reagents, and other disturbing causes may produce in the arrangement of the elementary parts of various textures.

To these we will add another requisite not more important for microscopical than for other inquiries; namely, a freedom from preconceived views or notions of particular forms of structure, and an absence of bias in favour of certain theories, or strained analogies. The history of science affords but too many instances of the baneful influence of the *idola specûs* upon the ablest minds; and it seems reasonable to expect that such creatures of the fancy would be especially prone to pervert both the bodily and the mental vision, in a kind of observation which is subject to so many causes of error, as that conducted by the aid of the microscope.

Finally, the sagacious Haller perceived, how necessary to the furtherance of physiology is a knowledge of *Organic Chemistry;* and we could adduce many instances to prove, that the attention which has of late years been paid to this subject, has not been without its fruit, in giving us an insight into the nature of many functions, which, without it, we could not have obtained.

In the living body the most delicate chemical processes are unceasingly going on, for the formation of new compounds and the destruction or alteration of old ones. It is evident that no progress can be made in the investigation of these invisible processes, unless we can arrive at an exact knowledge of the chemical composition of the various substances which are employed in them.

Henceforward, in physiological research, anatomical and chemical analysis must go hand in hand: the former to ascertain the minute mechanism of the various processes; the latter, to determine the nature of the affinities by which the syntheses and analyses of the living laboratory are effected.*

* In the composition of the preceding chapter we have to acknowledge valuable aid derived from the following works:—Haller, Elementa Physiologiæ Corporis Humani; Barclay on Life and Organization; Roberton on Life and Mind; Prichard on the Doctrine of a Vital Principle; Dr. Carpenter's article Life, and Dr. Alison's article Instinct, in the Cyclopædia of Anatomy and Physiology; Remarks on Scepticism, by the Rev. Thomas Rennell; Daniell's Chemistry; Graham's Chemistry.

CHAPTER I.

SOLID AND FLUID CONSTITUENTS OF ANIMAL BODIES.—PROXIMATE PRINCIPLES.—SECONDARY ORGANIC COMPOUNDS.—CLASSIFICATION OF THE TISSUES.—DEVELOPMENT OF THE TISSUES FROM CELLS.—PROPERTIES OF THE TISSUES.

Animal bodies are composed of solids and fluids. The former constitute the various textures and viscera; the latter, the blood, lymph, chyle, and the liquid secretions of glands contained, either in their excretory ducts, or in special reservoirs.

The solid textures contain only about one fourth of solid matter, the rest is water. The great shrinking which they experience, when dried, shews how much of their bulk they owe to this combination; and parts thus shrunken swell out again, and assume their natural condition on the addition of water. The mummy of a large man is of a very trifling weight. Blumenbach possessed the entire *perfectly dry* mummy of a Guanche or aboriginal inhabitant of Teneriffe, presented to him by Sir Joseph Banks, which, with all its muscles and viscera, weighed only seven pounds and a half.

Water is one of the most important constituents of animal bodies. It forms four fifths of their nutrient fluid, the blood; and it gives more or less of flexibility and softness to the various solid textures. The loss of it in great quantity speedily puts a stop to vital action, as may be easily shewn in the lower animals; and some animalcules, in which all appearance of life may have ceased on being deprived of it, will revive on its being supplied to them again. It is a solvent of many organic matters; some also are suspended in it: it is, therefore, a valuable medium for conveying these substances to the several textures and organs. It plays a most important part in the various chemical operations of the body; and its addition to, or subtraction from a particular compound is capable of converting it into a substance of very different properties.

By anatomico-physiological analysis we separate the solids and fluids of the body into their various kinds, and classify and arrange them according to their characters and properties.

By chemical means we obtain from them a class of substances, called *proximate principles,* substances but one step removed from the organized tissue, some of which are held in solution in the blood. These, in combination with sulphur, phosphorus, and other simple substances (incidental elements), and salts, form the material out of which the organized tissues are framed.

The general chemical constitution of these proximate principles has already been discussed in the Introduction; and they have been distinguished from another class of organic substances, *the secondary organic compounds,* among which we must particularise those which are formed by chemical action in the living organism, from materials furnished by it. These are found in various secreted fluids, and are easily obtained from them, either by spontaneous separation, or by simple chemical means; and they must not be confounded with a vast variety of compounds, which the chemist can create at will, both from them and from the proximate principles, through the affinities of various chemical substances for them.

The following table contains a list of substances which, in the present state of our knowledge, may be properly assigned to the two classes of organic compounds, to which allusion has been made:—

PROXIMATE PRINCIPLES.		SECONDARY ORGANIC COMPOUNDS.	
Albumen.	Compounds of Proteine.	Urea;	in the Urine.
Fibrine.	Compounds of Proteine.	Uric or Lithic acid;	in the Urine.
Caseine.	Compounds of Proteine.	Cholesterine; in the Bile,	
Gelatine.		Biliary matters.	
Chondrine.		Pepsine; in the Gastric juice.	
Elaine.		Sugar of milk.	
Stearine.		Lactic acid.	
Margarine.			
Hæmatosine.			
Globuline.			

Of the Proximate Principles.—1. *Albumen.*—This substance is so called from the white colour it possesses in the solid state. It is very readily obtained from the white of egg, *ovalbumen.* In the human body it exists in two states: fluid, being dissolved in the serum of the blood, and in some of the secretions; and solid, forming certain of the tissues, which are thence called albuminous tissues. These are, the brain, spinal cord and nerves, and the mucous membranes; it also enters into the composition of the muscles, and of the aqueous and vitreous humours of the eye. It is also contained in the effusions of serum or pus, which are the products of disease.

Albumen may be readily made to pass from the fluid to the solid state, or to coagulate, by the influence of certain reagents; but it has no spontaneous tendency to assume the solid form, except by the loss of the water which is combined with it. By evaporating white of eggs, at a temperature not exceeding 120°, its water is driven off, and solid albumen, in the form of a yellowish transparent brittle mass, is obtained with all its properties unimpaired. If a solution of albumen, as serum of the blood, be exposed to a heat between 140° and 150°, it coagulates, and then it becomes insoluble in water.

The mineral acids have the property of coagulating albumen. Of these, that which is most used in medical practice is the nitric, a drop or two of which will readily detect a small quantity of albumen dissolved in a clear fluid, by rendering it more or less opaque. Alcohol also has this property; and hence any albuminous textures submitted to its influence become hardened and condensed. Bichloride of mercury exercises a similar influence, and is a delicate test for albumen. It was Orfila who first employed this proximate principle as an antidote to the poisonous effects of the bichloride, which combines with the albumen and is by it partially converted into calomel. According to Peschier, the white of one egg is sufficient to render four grains of the poison innocuous.

Another delicate test for albumen is the ferro-cyanide of potassium, which will precipitate it from solution, provided a little acetic acid have been previously added, in order to neutralise the soda in combination with it. Albumen is also precipitated from solution by tannin.

Albumen coagulates at the negative pole of the galvanic battery, or at both poles, when a strong battery is employed.

Many other reagents will coagulate this principle, but enough have been mentioned for all practical purposes.

It often happens that albumen is carried off from the system in large quantities by the urine. By any of the means above-mentioned, its presence in that fluid may be detected. When heat is used, it will always be advisable to ascertain previously whether the urine be acid or alkaline; for the presence of alkali prevents the coagulation of albumen by heat. Hence it is a good rule, in testing for this substance, to employ both heat and nitric acid.

Albumen is soluble in caustic alkalies.

The existence of sulphur as a constituent of albumen, is shewn by the blackening of silver that has remained long in contact with it.

According to Mulder, this principle yields the following elements in one hundred parts:

Nitrogen	15·83
Carbon	54·84
Hydrogen	7·09
Oxygen	21·23
Phosphorus	0·33
Sulphur	0·68
	100·00

2. *Fibrine.*—This proximate principle forms the basis of the muscles; and is, therefore, the chief constituent of the flesh of animals, in which it is found in the solid form. It exists in a state of solution, in the serum of the blood, forming, with that fluid, the *liquor sanguinis* of Dr. Babington, in the lymph, and in the chyle. It is a constituent of the exudation (coagulable lymph) which forms on certain surfaces, as the result of the inflammatory process, and it sometimes occurs in dropsical fluids.

Fibrine is distinguished from the other proximate principles, by its remarkable property of *spontaneous coagulation.* When blood is drawn from a vein, and allowed to rest, it speedily separates into a solid portion, the *crassamentum* or *clot,* and a fluid portion, the *serum.* The former consists of fibrine, with the red particles entangled in it during its coagulation. It sometimes happens, that, owing to an unusual aggregation of the red particles together, and to their more speedy precipitation, a portion of fibrine on the surface coagulates without enclosing the colouring matter. A yellowish white layer forms the upper stratum of the crassamentum, and this is called the *buffy coat* or *inflammatory crust.* It is an example of nearly colourless fibrine, but contains also peculiar globules.

We may obtain fibrine in a state of considerable purity, by cutting the crassamentum into slices, and washing them in clean water so as to dissolve out the colouring matter; or by briskly stirring, with a bundle of twigs, blood as it flows from a vein: the fibrine coagulates upon the twigs in small portions, which, being washed, afford good specimens of colourless fibrine; by digesting afterwards in alcohol and ether, the adhering impurities are got rid of. Another mode of obtaining this substance is that suggested by Müller, namely, to filter frog's blood, the red particles of which being too large to permeate the pores of the filter, the liquor sanguinis passes through in a colourless state, and its fibrine coagulates free from colouring matter. Sometimes we obtain masses of fibrine, great part of which is colourless, from the cavities of the heart, and from the large arteries, after death. It is also accumulated, and disposed in a peculiar lamellar form, in the sacs of old aneurisms.

Pure fibrine is white, tasteless, and inodorous; it tears into thin laminæ, which are transparent, and it is remarkably elastic; by drying, it becomes yellow, hard, and brittle, and loses three fourths of its weight, but imbibes water again when moistened: it is insoluble in both hot and cold water, in alcohol, and in ether. By long-continued boiling in water, its composition is changed, and it becomes soluble. Strong acetic acid converts it into a jelly-like mass, which is sparingly soluble in water. All the alkalies dissolve fibrine. Any of these solvents of fibrine will prevent the coagulation of blood, which has been allowed to drop into it as it flows from the blood-vessels.

Fibrine is dissolved by cold concentrated muriatic acid, and, if kept at a cool temperature for twenty-four hours, the solution acquires an indigo-blue colour. Albumen, similarly treated, assumes a violet colour.

Caustic potash, common salt, carbonate of potash, and many neutral salts, when mixed in certain quantities with the blood, have the property of preventing the coagulation of its fibrine.*

We subjoin the ultimate analysis of fibrine, as given by Mulder. In one hundred parts, he found

Nitrogen	15·72
Carbon	54·56
Hydrogen	6·90
Oxygen	22·13
Phosphorus	0·33
Sulphur	0·36
	100·00

3. *Caseine.*—This principle has many properties in common with albumen and fibrine. It is found abundantly in milk; its occurrence in other fluids has not been positively determined. The curd, which is formed by heating milk in which a free acid existed, consists of a combination of caseine with the acid. Heat alone will not effect the precipitation of the curd; but the addition of a little acid of any kind will occasion it.

When dilute sulphuric acid is added to skimmed milk, a precipi-

* See further observations on the results of the examination of fibrine by the microscope, in the chapter on the Blood.

tate occurs, which is sulphate of caseine. By digesting the clot, thus formed, with water and carbonate of lime, the acid combines with the lime, and the caseine, set free, dissolves in the water, and may be obtained by evaporation.

Caseine is coagulated very perfectly by the action of rennet (the fourth or true digesting stomach of the calf) aided by heat. This power of coagulating caseine is not to be attributed to the acid of the calf's stomach, but to the organic principle (pepsine) resident in it; for the power remains, after all evidence of acid reaction has been removed. This is one of the most powerful agents in causing the coagulation of caseine, and it has been employed in domestic œconomy for the manufacture of cheese, which consists of the curd mixed with butter, compressed and dried. So perfect is the coagulating power of rennet, that not a particle of caseine in milk submitted to its action will remain uncoagulated.

Caseine comports itself with reagents in a manner very similar to albumen. In the coagulated state it is insoluble in water, but soluble in liquor potassæ. It is not precipitated by heat alone, in which respect it differs from albumen. Acetic acid, which will not precipitate albumen, causes the coagulation of caseine, and an excess of acid again dissolves it.

Caseine contains sulphur, but no phosphorus.

Mulder's ultimate analysis is as follows:

Nitrogen	15·95
Carbon	55·10
Hydrogen	6·97
Oxygen	21·62
Sulphur	0·36
	100·00

If albumen, or fibrine, or caseine, be dissolved in a moderately strong solution of caustic potash, and exposed for some time to a high temperature, it becomes decomposed; and if acetic acid be now added, a precipitate takes place of a gelatinous translucent matter. This substance was discovered by Mulder, and named by him *Proteine* (from the Greek verb πρωτευω, I am first), as being the radicle of these proximate principles; or, in the language of Liebig, the commencement and starting-point of all the tissues: so that it appears that each of these principles is composed of this substance, with the addition of certain proportions of phosphorus, sulphur, or of both. In the process by which it is obtained, the object is to remove the sulphur and phosphorus and any salts which may be mixed with it, and to set the proteine free.

Proteine, when dried, forms a hard, brownish-yellow substance, without taste, and insoluble in water and alcohol. It attracts moisture from the air, and swells out again into a gelatinous mass when moistened. It is soluble in all acids, when diluted; and forms combinations with them, which are with difficulty, or not at all, soluble in excess of acid. It is also dissolved in dilute alkalies, or in solutions of alkaline earths.

The ultimate analysis of proteine, according to Mulder, from one hundred parts gives as follows:

Nitrogen	16·01
Carbon	55·29
Hydrogen	7·00
Oxygen	21·70
	100·00

The following table exhibits the relations which albumen, fibrine, and caseine bear respectively to proteine:

Albumen of Serum	= 10 eqts. Proteine + 1 eqt. Phosph. + 2 eqts. Sulph.
Albumen of Egg	= 10 eqts. Proteine + 1 eqt. Phosph. + 1 eqt. Sulph.
Fibrine	= 10 eqts. Proteine + 1 eqt. Phosph. + 1 eqt. Sulph.
Caseine	= 10 eqts. Proteine + 1 eqt. Sulph.

Besides the essential elements of these proximate principles, which are obtained by their ultimate analysis, we find certain salts mixed with them. In albumen, phosphates and sulphates of earths and alkalies and chloride of sodium; in fibrine, phosphate of lime; and in caseine, the same salt, in the proportion of 6·24 per cent. As the phosphate of lime is the same as bone-earth, the existence of it in union with the proximate principle, which forms the chief constituent of milk, seems to have reference to the process of ossification during the growth of the infant.

Proteine, in every respect the same as that which forms the basis of the proximate principles just described, may be obtained from similar elements in the vegetable kingdom. Gluten, which exists abundantly in the seeds of the Cerealia, yields a principle which is called *vegetable fibrine;* the same substance coagulates spontaneously in the newly expressed juice of vegetables. From the clarified juices of cauliflower, asparagus, mangel-wurzel, or turnips, when made to boil, a coagulum is formed, which cannot be distinguished from the coagulated albumen of serum or the egg. This is *vegetable albumen.* And in peas, beans, lentils, and similar leguminous seeds, we find a substance similar to caseine. It is *vegetable caseine,* which, like the animal principle of the same name, does not coagulate by heat alone, but yields a coagulum on the addition of an acid, as in milk. "The chemical analysis of these three substances," says Liebig, "has led to the very interesting result, that they contain the same organic elements, united in the same proportions by weight; and, what is still more remarkable, that they are identical in composition with the chief constituents of blood, animal fibrine, and albumen. They all three dissolve in concentrated muriatic acid with the same deep purple colour; and, even in their physical characters, animal fibrine and albumen are in no respect different from vegetable fibrine and albumen. It is especially to be noticed, that by the phrase, identity of composition, we do not here imply mere similarity; but that, even in regard to the presence and relative amount of sulphur, phosphorus, and phosphate of lime, no difference can be observed."

4. *Gelatine.*—This substance exists in a peculiar combination with the tissues of which it forms a constituent, and can only be obtained by artificial means. If the cutis or true skin, tendon, or bone, be subjected to continued boiling, this substance is obtained in solution in the hot water, and upon cooling assumes the form of a solid jelly, which is the more solid as the quantity of water contained in it is less. The textures which yield gelatine are, the white fibrous tissue, areolar tissue, skin, serous membranes, bone. Glue prepared from hides, &c.; size, from parchment, skin, &c.; and isinglass from the swimming-bladder of the sturgeon, are various forms of gelatine used in commerce.

Gelatine, obtained by boiling, is in combination with a considerable quantity of water: by a slow and gentle heat this may be driven off, and the gelatine obtained in a dry state. Dry gelatine is hard, transparent, colourless, without smell or taste, of neutral reaction; in cold water it softens and swells up, and dissolves in warm water. It is insoluble in alcohol and ether, but very soluble in the dilute acids and alkalies. When tannin, or the tincture or infusion of galls, is added to its solution in water, a brownish precipitate is thrown down — the *tanno-gelatine,* which may be precipitated from a solution of gelatine in 5000 times its weight of water.

The process of tanning leather results from the affinity of gelatine for tannin. The skins of the animals having been first freed from cuticle and hairs by soaking in lime-water, are tanned by submitting them to the action of infusion of oak-bark, the strength of which is gradually increased until a complete combination has taken place. An insoluble compound is thus formed, capable of resisting putrefaction.

According to Mulder, gelatine contains in one hundred parts,

Nitrogen	18·350
Carbon	50.048
Hydrogen	6·477
Oxygen	25·125
	100·000

to which may be added some inorganic material, chiefly phosphate of lime.

Dr. Prout remarks, that gelatine in animals may be said to be the counterpart of the saccharine principles of plants; it being distinguished from all other animal substances by its ready convertibility into a sort of sugar, by a process similar to that by which starch may be so converted. If a solution of gelatine in concentrated sulphuric acid be diluted with water and boiled for some time, gelatine-sugar may be obtained from it, on saturating with chalk. Again, by boiling gelatine in a concentrated solution of caustic alkali, it is separated into *leucine* and gelatine-sugar, or *glycicoll.* The latter product crystallizes in pretty large rhomboidal prisms; is colourless, inodorous, and very sweet.* It differs from sugar, however, in the important particular, that it contains nitrogen; and Mulder assigns to it the following formula, $C_8\ H_7\ N_2\ O_5 + 2\ HO$.

Proteine cannot be obtained from gelatine; but it seems reasonable to infer, that it or its compounds must have contributed to the formation of the latter substance, for, in the egg, the gelatine of the chick cannot be derived from any other material than a compound of proteine. Scherer has shewn that gelatine contains the elements of two equivalents of proteine, with three of ammonia, and seven of water.

5. *Chondrine* is a substance in many respects similar to gelatine. It is obtained in a state of solution, by boiling water, from the permanent cartilages and from the cornea; also from the temporary cartilage prior to ossification; it gelatinizes on cooling, and when

* Graham's Chemistry, p. 1039.

dry assumes the appearance of glue. It differs from gelatine, in not being precipitated by tannin, and in yielding precipitates to acetic acid, alum, acetate of lead, and the protosulphate of iron, which do not disturb a solution of gelatine. It resembles the proteine compounds in containing a minute quantity of sulphur.

Mulder's analysis of one hundred parts is,

Nitrogen	14·44
Carbon	49·96
Hydrogen	6·63
Oxygen	28·59
Sulphur	0·38
	100·00

Respecting the remaining substances included in the list of true proximate principles, very few words are necessary, as they will be more fully treated of in subsequent chapters.

Elaine, *Stearine*, and *Margarine* are proximate principles of fat, and are found also in the brain and nerves. Stearine exists but sparingly, or not at all, in human fat.

Hæmatosine and *Globuline* are the constituents of the particles, or corpuscles, to which the blood owes its colour. They are both nearly allied to albumen; and the latter is regarded as a compound of proteine.

The proximate principles which have been described in the preceding paragraphs are constituents of the animal food, upon which the human race, and the inferior creatures, to a great extent subsist; and the discovery that similar principles exist in the vegetable kingdom, also adapted for food, is of the highest interest, as proving that both kingdoms of organized nature are capable of affording the materials which are suited to supply the waste in the animal tissues which is the necessary result of their vital actions. The blood is the immediate *pabulum* of the tissues; its composition is nearly or entirely identical with them; it is, indeed, as Bordeu long ago expressed it, liquid flesh; it contains the elements of the solids in a state of solution — *le sang est de la chair coulante.* The proteine compounds more immediately contribute to the formation of the blood, and, as we have seen, may be obtained directly from that fluid; and the process of nutrition consists in the attraction of certain of these principles from the blood, and the appropriation of them by the textures and organs, in a form assimilated to that of their elementary parts.

It is necessary to the support of nutrition, that these proximate principles should be supplied in proper quantity to the blood, from time to time, together with a due proportion of water; and as the human body is composed of a variety of textures, differing in their chemical composition so a variety of food is required for its perfect nourishment. This statement, which appears most reasonable prior to experience, is fully borne out by the results of the various experiments on the nutritive power of different substances, from the time of Papin to the present day. No one proximate principle is of itself adequate to support life: if any such substance be administered alone to animals, they will perish sooner or later, with signs of waste and destruction in various textures. This had been long ago ascertained respecting gelatine; but a commission appointed by the French Academy have lately reported that it applies equally to albumen, caseine, or fibrine, if employed alone; and that neither animals nor man should be restricted to any course of diet, which does not contain *all* the proximate elements of their frame.

These facts should be made known to, and impressed upon all, whose position in society leads them to superintend the administration of food to a number of human beings congregated in prisons, workhouses, or other public institutions. A complex machine, made up of many different kinds of substances, requires for its repair a corresponding variety of materials. The fabric of man's body is a piece of mechanism compounded of divers parts, derived from albumen, fibrine, gelatine, &c.; and the material, which is to supply the wear and tear that continually go on in it, ought to contain these substances. It is even more important for sufficient nourishment that attention should be paid to the *quality* than to the quantity of the food administered.

By the function of digestion, a fluid (*the chyle*) is prepared, which contains those constituents of the food that are adapted to nourish the body, and the first step of the nutrient process consists in the addition of this new supply of nutritious material to the blood. A further stage of this process is that whereby the several proximate principles are separated in order to be applied to the support of their appropriate textures; as albumen, to the albuminous tissues; fibrine, to the fibrinous. These two principles have already appeared in the chyle, and pass with it into the blood-vessels, in which all the changes necessary to nutrition take place. It is probable that gelatine is formed in the blood, but is attracted from it by its proper tissues immediately upon its formation, so that it does not accumulate in it; and this accounts for our not being able to find it in the blood. The fatty elements also separate in the blood, and are destined to nourish the adipose tissue, and the nerves. It may be fairly conjectured that the development and separation of these principles take place in the capillary blood-vessels, because those vessels penetrate and play freely among the elementary parts of the tissues; and also because the blood does not manifest a decided change in its characters until it has passed through that part of the sanguiferous system.

The blood is likewise the seat of other changes, not less important to the well-being of the animal œconomy. As certain particles of the various tissues become effete and useless, they are removed either by a direct absorbing power of the blood-vessels, or by that of certain vessels, called lymphatics, and thus they again find their way into the current of the circulation. Here the elements of the tissues, by some unknown chemical agency, undergo certain transformations, and the *secondary compounds* are formed, to be excreted from the system by means of particular organs. Urea and uric acid, thus formed in the blood, are excreted by the kidneys; lactic acid, by the kidneys and the skin; the elements of the bile, by the liver, &c. &c. But whilst it is highly probable that the effete particles furnish materials for these compounds, there seems good reason to believe, that, at least with respect to some of them, the food likewise contributes immediately to their formation. That this is the case with respect to the bile, is rendered very likely by several circumstances which cannot be dwelt upon at present.

In the present state of our knowledge, it is impossible to assign the particular tissues whose metamorphoses give rise to the formation of certain *secondary* compounds. Dr. Prout has expressed the opinion that urea is derived from the gelatinous, and uric acid from the albuminous tissues. And it may be conjectured, that the fatty tissues afford material for the formation of some of the constituents of the bile.

As each of these secondary organic compounds forms a component part of some special secretion, it would be premature to do more at present than allude to them; we, therefore, postpone the further investigation of them to those parts of the work where the respective secretions will be treated of.

Classifications and Properties of the Tissues.— From the proximate principles, the various textures are produced by the development of particular organic forms. It has already been stated, that the simplest form which animal matter assumes in its organization is that of a nucleated cell. Such cells exist in vast numbers, free and isolated, floating in the blood, but having occasionally a remarkable tendency to cohere. These are the red particles of the blood, which perform some very important office in reference to that fluid and the different tissues, as appears from the serious results consequent upon a great deficiency of them. They may be considered to be among the simplest products of organization.

In the embryonic state all the tissues are composed of cells, analogous in structure to the corpuscles of the blood. These are united together by a more or less abundant intercellular substance, which is either homogeneous (*hyaline*), minutely granular, or indistinctly fibrous. Some tissues retain, as their permanent character, this cellular structure; whilst in others the cells undergo certain metamorphoses by which they are converted into other forms, which constitute the anatomical elements of the adult textures.

It seems impossible to devise a satisfactory arrangement of the tissues, which shall be based on one principle of classification. The following table has been constructed chiefly with the object of presenting to the reader a general view of the various tissues, the anatomical characters of which will be discussed in subsequent pages.

TABULAR VIEW OF THE TISSUES OF THE HUMAN BODY.

1. Simple membrane, homogeneous, or nearly so, employed alone, or in the formation of compound membranes.	Examples.—Posterior layer of the cornea.—Capsule of the lens. —Sarcolemma of muscle, &c.
2. Filamentous tissues, the elements of which are real or apparent filaments.	White and yellow fibrous tissues. —Areolar tissue.
3. Compound membranes, composed of simple membrane, and a layer of cells, of various forms (epithelium or epidermis), or of areolar tissue and epithelium.	Mucous membrane. — Skin. — True or secreting glands. — Serous and synovial membranes.
4. Tissues which retain the primitive cellular structure as their permanent character.	Adipose tissue. — Cartilage. — Grey nervous matter.
5. Sclerous or hard tissue.	Bone.—Teeth.
6. Compound tissues.	
a. Composed of tubes of homogeneous membrane, containing a peculiar substance.	Muscle.—Nerve.
b. Composed of white fibrous tissues and cartilage.	Fibro-cartilage.

The first texture enumerated in this table is an example of the simplest form of membrane. Its principal character is extension; but as to the arrangement of its ultimate particles nothing is known; for, under the highest powers in the microscope it appears homogeneous, that is, without visible limits to its particles, or, at most, irregularly and very indistinctly granular. The capsule of the lens, the posterior layer of the cornea, and the walls of the primary organic cells, are composed of it; and it is employed in forming muscle, nerve, and the adipose and tegumentary tissues.

The filamentous tissues are extensively used for connecting different parts, or for associating the elements of other tissues. The ligaments of joints, for instance, are composed of the white or yellow fibrous tissues; and areolar tissue surrounds and connects the elementary parts of nerves and muscles, accompanies and supports the blood-vessels, and unites the tegumentary tissues to their subjacent parts or organs.

Under the title *compound membranes* we include those expansions, which form the external integument of the body, and are continued into the various internal passages, which, by their involutions, contribute to form the various secreting organs or glands. These are composed of the simple homogeneous membrane, covered by epidermis or epithelium, and resting upon a layer of vessels, nerves, and areolar tissue in great variety; and they constitute the skin, and mucous membranes, with the various glandular organs which open upon their surface. Hairs and nails, being hardened cuticle, are justly regarded as appendages to the former.

To these, we may add those remarkable membranes, composed of areolar tissue and a thin indusium of epithelium, which are employed as mechanical aids to motion. These are the serous membranes which line the great cavities of the body, and the synovial membranes, which are interposed between the articular extremities of the bones in certain joints, or are connected with and facilitate the motions of tendons.

The tissues which compose the fourth class have no common character, except their adherence, in the adult state, to the primitive cellular structure, and their analogy in that particular with the vegetable tissue. Although a certain agreement, in morphological characters, allows these textures to be grouped together, none can be more dissimilar as regards their vital endowments. They differ materially as to the degree of cohesion between their cells: in cartilage there is generally a firm and resisting intercellular substance; in adipose tissue, the interval between the cells is occupied by areolar tissue and blood-vessels, which are foreign to the true adipose cells; and, in the grey nervous matter, vessels and nerve tubes exist between the cells.

The sclerous tissue (σκληρος, hard,) contains a large proportion of inorganic material, to which it owes its hardness; it differs very materially from all the other tissues, excepting cartilage and fibro-cartilage, which, as regards hardness, might be classed with it.

The compound tissues are those, the elementary parts of which are made up of two distinct tissues. Thus both muscle and nerve are composed of parallel fibres or threads, each fibre being compound; in muscle, it is composed of homogeneous membrane, disposed like a tube, containing a fleshy (*sarcous*) substance, arranged in a particular manner, which is the seat of the vital properties of the tissue; and, in nerve, the fibres are composed of similar tubes of homogeneous membrane containing an oleo-albuminous substance, *neurine*. Fibro-cartilage is also properly a compound texture, being made up of white fibrous tissue and cartilage; it is employed almost exclusively in the mechanism of the joints of the skeleton, in which it is associated with bone, cartilage, and ligaments.

Of the Development of the Tissues from Cells.—At the earliest period of embryonic life, the process of organization has advanced to so slight an extent, that the variety of textures above described has not yet appeared.

The prevailing mode, in which the development of animals takes place is, by the formation, within the parent, of a body containing the rudiments of the future being, as well as a store of nutrient material sufficient to nourish the embryo for a longer or shorter period. This body is called the *ovum* or egg. It is of that form which, in a former page (p. 9, fig. 1), has been described and delineated as the simplest which organization produces. It consists of a vesicular body filled by a fluid, and enclosing another, within which is a third, consisting of one or more minute, but clear and distinct granules. The first, or the *vitelline* membrane of the ovum, is the wall of a cell; it is composed of homogeneous membrane: the second, or the *germinal vesicle* of the egg, is the nucleus of the first: and the third, which is called by embryologists the *germinal spot*, is a *nucleolus* to the second. It appears, from the researches of Wagner and Barry, that the nucleus or germinal vesicle precedes the formation of the vitelline membrane, but the precise relation as to the period of its formation of the nucleolus or germinal spot to the nucleus has not yet been satisfactorily made out. The germinal vesicle and spot become the seat of a series of changes, which give rise to the development of new cells, for the formation of the embryo.

At this period the embryo consists of an aggregate of cells, and its further growth takes place by the development of new ones. This may be accomplished in two ways: first, by the development of new cells within the old, through the subdivision of the nucleus into two or more segments, and the formation of a cell around each, which then becomes the nucleus of a new cell, and may in its turn be the parent of other nuclei; and, secondly, by the formation of a granular deposit between the cells, in which the development of the new cells takes place. The granules cohere to each other in separate groups here and there, to form nuclei, and around each of these a delicate membrane is formed, which is the cell-membrane. The nuclei have been named *cytoblasts*, because they appear to form the cells (*κυτος*, cell; *βλαστεω*, to produce); and the granular deposit in which these changes take place is called the *cytoblastema.*

In every part of the embryo the formation of nuclei and of cells goes on in one or both of the ways above-mentioned; and, by and by, ulterior changes take place, for the production of the elementary parts of the tissues. The precise share which the cells take in this process cannot be made intelligible in the present stage of our inquiry, even if observers were agreed in their accounts of the phenomena. It must suffice for us now to explain, as far as we are able, the general changes that occur, and the probable office which each part of the cell performs in them.

The changes which the cells undergo in the formation of the tissues, may be described under two heads: first, those affecting the cell-membrane; and, secondly, those in which the nucleus is concerned. In those tissues, whose ultimate elements are fibrous, that is, consisting of real or apparent fibres, as areolar and fibrous tissues, the cell-membranes become elongated, and so folded or divided as to give the appearance of a subdivision into minute threads or fibres. In the tissues, which are composed of tubes of homogeneous membrane containing a peculiar substance within them, as muscle and nerve, the cells are joined end to end, and, the partitions at each extremity being removed, their cavities communicate, so that they together form a tube, or sheath, in which the deposit of the proper muscular or nervous substance takes place. The smallest or capillary blood-vessels also are formed by the coalescence of the walls of the cells, not at one or two, but at several points, owing to their elongation, here and there, into pointed processes, which unite and form the ramifications of the vessels.

In these examples, the nucleus of the cell appears to take no part in the formation of the tissue. What becomes of it? does it become absorbed, or does it waste away, its office having ceased? There is abundant evidence to shew that the nuclei are still persistent in the fully formed tissues, for they have been seen in all those enumerated in the last paragraph. They are generally altered in form, being flattened and elongated. Henle believes that, while they retain their peculiar characters, they are prolonged at either pole into peculiar fibres, distinct, in anatomical and chemical characters, from the proper fibres of the tissue: he designates the latter *Zellenfasern*, cell-fibres; and the former *Kernfasern*, nucleus-fibres. For instance, the two elements of areolar tissue, which will be described at a future page, are derived, according to him, the white fibrous element, from the cell; the yellow, from the nucleus. The formation of the homogeneous simple membrane which forms the basement of the skin and mucous membrane, may be ascribed to the flattening and fusion of the cell-walls into one another. The free surface of these membranes, wherever they may be found, whether as integuments to the body, or folded into glands, is the seat of a continual development of new cells, which may have primarily sprung from the nuclei of the formative cells of the basement membrane.

In other tissues the walls of the cells become thickened by a deposition around and between them, with which they become united and incorporated, and thus an intercellular substance is formed. This substance becomes the seat of a further deposition, or new arrangement of particles, which, as far as we know at present, is not preceded by the development of cells. In cartilage, which in its simplest state is only an aggregate of cells, this substance assumes a fibrous form. In most textures, it is not improbable that the nuclei are persistent; in cartilage, they remain in the cell-cavities, and possibly contribute to the growth and nutrition of the cartilage; in bone they form the lacunæ from which minute canals are prolonged into neighbouring ones, or into the vascular channels; and, in teeth, they are probably converted into the dental tubuli.

From the preceding brief and necessarily imperfect sketch, it seems evident, that, in the various metamorphoses of the fœtal into the perfect tissues, both the elements of the cells take a part. In no instance does there appear to be an actual conversion of either cell-wall or nucleus into the ultimate elements of the tissues. The cell-walls may be changed into a part, *accessory* to the complete texture, as the sarcolemma or sheath of the muscular fibre; but the further organizing process takes place on its outer or inner surface. And the nuclei, likewise, may be changed into parts, which contribute to the nutrition of the tissue; but not into its essential elements. These, it must be remarked, are always the product of an ulterior organizing process, connected chiefly with the cell-wall.

There seems reason to believe, that, during the organizing process, which occurs simultaneously with the changes of the cell, a chemical alteration takes place; for the cells of cartilage sometimes contain fat, and the cartilage of bone prior to ossification contains chondrine, but, after the ossific process, gelatine is found: and it is also stated, that the element which may be obtained from the young cells of areolar tissue is pyine; whereas gelatine is yielded by the fully formed tissue.

The formation of cells does not cease with the infancy of the organism. These minute organic elements are most important agents in various functions of the body at every period of its existence. By them the secretions are separated; and it is not improbable that they contribute largely to those changes in which nutrition immediately consists. They are found floating in immense numbers in the blood, as well as in the chyle and lymph; and, even in diseased secretions, as pus, they exist in great quantity. In the inflammatory process, they are formed in great abundance; and in the malignant growths, which infest the body, so as to manifest themselves at different parts of it, such as the various forms of cancer, the same organic forms are to be found.

In short, Schleiden and Schwann have proved that the nucleated cell is the agent of most of the organic processes, whether in the plant or animal, from the separation of the embryo from its parent, to the development, growth, and nutrition of the adult individual.

Properties of the Tissues.—The fully grown tissues manifest differences among themselves, not merely by their anatomical characters, but by their properties. These may be conveniently sub-divided into *physical* and *vital.* Strictly speaking, this is a distinction without a difference; for doubtless all the properties of animal tissues may be ascribed to the peculiar arrangement of their particles, and are, therefore, physical. Our reasons for adopting the division will appear in explaining the nature of these properties.

The *physical* properties of the tissues are those which are dependent simply on the peculiar arrangement or mode of cohesion of their constituent particles, as well as upon their chemical constitution, and will manifest themselves in the dead, as distinctly as in the living, texture. The elasticity of yellow ligament, for instance, is as evident in a specimen which has been preserved in spirits for years, as in one taken fresh from the body. The *vital* properties are those which exist only during life, and which cease immediately molecular life has ceased. A muscle will contract only so long as it is alive: when dead, it refuses to respond to those stimuli, which so easily excited it while living.

The most striking physical property which certain tissues manifest, is that of *elasticity,* in virtue of which the tissue reacts, after a stretching or a compressing force has been withdrawn. The yellow ligament, which constitutes the ligamenta subflava of the vertebral laminæ, is as elastic as India-rubber; the middle coat of arteries manifests quite as much elasticity. Cartilage is flexible and elastic; and is extensively employed, in consequence of this property, to encrust the articular extremities of the bones, for their protection in the movements of the joints.

The existence of elasticity implies that of *extensibility.* All elastic tissues must admit of being stretched before they can manifest their elastic reaction. But some textures are extensible without being elastic. Such tissues yield only to a long-continued extending force; and, in the healthy state, they are capable of resisting such a force of tension for a considerable period. The resistance which a fibrous membrane offers to the enlargement of an organ or tumour, which it covers, illustrates this statement: the pain felt in hernia humoralis or inflammatory enlargement of the testicle, is doubtless due to the resistance of its fibrous coat to the swelling of the soft substance of the gland.

The various animal tissues exhibit a property of *porosity*, or evince a power of attraction for aqueous fluids. If a piece of areolar tissue from the axilla be soaked in water, it will imbibe it as freely as a sponge. Serous membranes, being chiefly composed of areolar tissue, have the same property, but to a less degree; and the coats of blood-vessels, and hollow membranous viscera, are also porous. The occurrence of transudations, through living and dead tissues, is explained by this property. When the blood is loaded with water, or its passage through the blood-vessels is impeded, or when the vital changes in the blood-vessels go on feebly and imperfectly, their walls exert a morbid attraction upon the water of the contained blood, which transudes into the surrounding areolar tissue, and gives rise to that dropsical effusion, which is commonly called Anasarca. In the minute capillary vessels, this property is always present in a state of health, and the nutrition of the surrounding tissues is effected by the exercise of it. After death, the influence of porosity is favoured by the total absence of motion in the fluids, and of vital change in the walls of the vessels; and, therefore, in the dead body, we find the areolar tissue more or less loaded with water in all those places in which gravitation favoured its accumulation. The progress of decomposition, by disintegrating the tissues, also favours the occurrence of transudation.

It is probable that certain vital processes consist solely in transudation. In this way the watery part of the secretions doubtless escapes from the blood-vessels, into the canals of the secreting organs; and this is especially likely as regards the mechanism of the kidney, where the blood-vessels of the Malpighian bodies, reduced to their minutest size, naked, and unassociated with any other tissue, are most favourably placed for the occurrence of this phenomenon; and the absorption of fluids brought in contact with certain surfaces is explicable on the same principle.

The process, which was first described by Dutrochet, under the name Endosmose and Exosmose, is intimately connected with the porosity of animal tissues. It is a process, "in which the mutual attraction of two liquids is called into action, one of which is more capable than the other of freely wetting a porous solid which forms part of the combination." *

If an animal bladder, the cæcum of a fowl, partially filled with syrup, and tied tightly at its open end with a string, be suspended in a vessel of water, it will soon be found distended almost to bursting, in consequence of a considerable quantity of the water having passed through the walls into the cavity of the bladder (*Endosmose*). If the exterior fluid be examined, a portion of the syrup will be found to have passed out of the bladder (*Exosmose*). Or the phenomenon may be illustrated by the following experiment:—Take a funnel, and tie over its broad end (of three or four inches' diameter) a piece of bladder, invert it, and fill it with spirits of wine, and fit to its small end a glass tube, three or four feet in length, and then place it in a vessel of water. In a short time the water will be observed to rise in the tube, and it will ultimately

* Daniell's Chemistry.

reach the top and flow over. "The first moving power here," says Professor Daniell, "is the force of adhesion between the water and the bladder; the former penetrates the pores of the latter, and comes in contact, upon its upper surface, with the spirit, by the attraction of which, it is removed from the bladder and mixes with its mass. The height of the column is in some degree the measure of the force thus called into action." The purely physical nature of this process is shewn by the fact that it will equally take place through porous inorganic substances, as through organic membranes. It would be impossible to do more here than give a brief explanation of this remarkable phenomenon. It is important to add, that the observations of Dutrochet clearly shew that the nature of the septum exerts an important influence upon the direction of the predominant current. If the attraction of the septum for the exterior fluid be the greater, the endosmotic current will prevail, and *vice versâ.*

Endosmose is a more important agent in the vital phenomena of plants than in those of animals. It is supposed, by some physiologists, to be brought into play in the processes of secretion and absorption.

The animal membranes exercise the property of porosity in reference to gases, as well as to liquids; and the tendency of dissimilar gases to become diffused among each other manifests itself even through compound textures. As in the case of liquids, there is a double current, when two dissimilar gases are separated by a porous septum, and the predominant current is that which has the strongest attraction for the septum. The following experiments illustrate this phenomenon:—Confine some common air in a jar, by tying tightly over it a piece of sheet-caoutchouc, and then place the jar under a large bell-glass filled with hydrogen gas; the hydrogen will gradually penetrate the partition, distend the caoutchouc, and ultimately burst it. Or, suspend a membranous bag, the stomach of a rabbit filled with common air, in an atmosphere of carbonic acid; the latter will penetrate to the former and burst the bag. In both instances there is an exosmose greatly inferior in the quantity of gas to the endosmose. In respiration, this phenomenon occurs at every inspiration through the walls of the pulmonary air-cells and the plexus of capillary vessels distributed upon them.*

Although in the manifestation of these phenomena there is no

* Daniell's Chemistry.

direct exercise of vital force, the tissues are not the less dependent on healthy vital action for the preservation of their peculiar properties in a state of integrity. Whoever will compare the compact figure of a vigorous healthy man, accustomed to field-sports and active exercises, with the relaxed, feeble, half-dislocated limbs of an ill-nourished, hysterical woman, will readily perceive how great an influence healthy nutrition must exert in preserving and improving the physical properties of the tissues.

The *vital properties* manifest themselves by a change which occurs in the molecules of certain tissues, as the result of a stimulus applied. The change, thus produced, may be evident from a visible alteration in the tissues stimulated; or it may shew itself through a secondary influence exerted upon some other texture or organ, with which the stimulated tissue may be in connexion.

These properties exist in two tissues, namely, in muscle and in nerve. A muscle, when stimulated, shortens itself; and, therefore, it is said to possess the property of *contractility*. This power of contracting, in obedience to a stimulus, is characteristic of muscle, and probably occurs in no other kind of animal texture. The stimulus may be direct irritation by mechanical means, or by galvanism, or by some chemical substance; but the natural one, during life, is propagated by the nerves.

In nerve, the vital changes are unaccompanied by any alteration in the tissue itself, which is appreciable by our senses. The excitation or irritation of the nerve may be manifested in three ways: first, by its inducing the contraction of the muscle which it supplies; secondly, by its exciting contraction, in muscles which it does not supply, through a change wrought in the nervous centre; thirdly, by its exciting a sensation. The same stimuli, which we have mentioned as capable of exciting muscular contraction, will produce these effects in nerves; and the will, and other emotions of the mind, are capable of stimulating nerves which are connected with the brain, and exciting action in the muscles to which they are distributed.

That a nerve, when irritated, may excite a sensation, it is necessary that it shall be in connexion with the brain. The bodily feelings of pain or pleasure are thus produced, through the medium of what are called *sensitive* nerves, or nerves of *common sensation;* and we say that the sensibility of any tissue is great or small, according as it is supplied with such nerves in more or less quantity. Tendon, in which probably few nerves exist, is a tissue of low sensibility; whilst the skin, which is largely supplied with nerves, is highly sensitive.

Light, sound, and the sapid and odoriferous qualities of bodies, are capable of stimulating certain nerves, and exciting appropriate sensations in the mind. The nerves which respond to such stimuli, are called nerves of *proper* or *special sensation;* and this name seems appropriate, because these nerves, when otherwise stimulated, excite only their peculiar sensations. If the optic nerve be mechanically irritated, a flash of light is produced; as sometimes occurs if the retina be touched by the needle in the operation for cataract. If the auditory nerves be stimulated by a galvanic shock, a sound is produced. Volta, who tried the experiment on his own person, perceived a hissing and pulsatory sound, which he compared to that of a viscid substance boiling: and Ritter relates, that, upon closing the circle when both his ears were included in it, he was sensible of the sound of G treble; if but one ear was in the circuit, and the positive pole applied to it, the sound was lower than G; if the negative pole was applied to the ear, the sound was higher.* These peculiarities of the nerves of proper sensation are due to the fact, that at their periphery they are so organized as to be admirably adapted for receiving the impressions of their special stimuli, and at their centres they are connected with those parts of the brain which take cognizance of these special agents. Thus the optic nerve is admirably disposed in the eye for the reception of luminous impressions, and the auditory nerve is beautifully adapted to receive the pulsations of sound, whilst each is connected with a different part of the brain; and what are called subjective phenomena of vision or hearing are often the result of local congestions of blood affecting the respective nerves of these senses, and producing mechanical irritation of them.

In the manifestation of the vital properties, under the influence of appropriate stimuli, it cannot be doubted that an organic molecular change is produced in nerve as well as in muscle. This may be considered as a polar state, in which the ultimate particles of the tissue assume a polarized condition, which may be fairly compared to that which friction or other means can produce in various substances by which they may be rendered mutually attractive or repulsive. In muscle, it becomes at once evident by the powerful attraction which is exerted between its particles, by which the shortening is effected. In nerve, it is shewn by the rapidity with

* Müller's Physiology, translated by Baly.

which the change excited by the stimulus at one part of the nerve is conveyed throughout its course to the muscle, or to the brain or other nervous centre, with which it may be connected, producing in them the same or an analogous state.

As these phenomena occur in tissues, whose chemical composition is more complex than that of any others in the body, and which are the seat of continual changes, they are subject to many disturbing causes, and are easily affected by slight modifications in the general state of the system. Many substances quickly exert an influence upon them, as opium, strychnine, and various sedatives, narcotics, or stimulants. Those properties are therefore entirely dependent on the nutrition of their respective tissues; they quickly vary with the state of that function, and when it ceases, in death, they vanish with it.*

* For information upon the subjects treated of in this chapter we refer to the following sources:—Henle, Algemeine Anatomie; Berzelius, Chimie Organique, Fr. edit. 1833; Prout on Stomach and Urinary Diseases; Liebig's Animal Chemistry, by Gregory; Graham's Chemistry; Daniell's Chemistry; Schwann, Mikroskopische Untersuchungen über die Uebereinstimmung in der Struktur und dem Wachsthum der Thiere und Pflanzen; Dutrochet, article Endosmose, in the Cyclopædia of Anatomy and Physiology.

CHAPTER II.

FUNCTIONS. — ANIMAL MOTIONS. — MOLECULAR MOTION. — ORGANIC MOLECULAR MOTION. — MUSCULAR MOTION. — CILIARY MOTION. — MOTIONS OF SPERMATOZOA.

The subdivision of the functions of the human organism into the animal and the organic, as already stated, may be adopted as the least objectionable basis for their arrangement. Under the former title we include those functions, which are peculiar to and characteristic of the animal part of the living creation, and to which there is nothing similar or analogous in the vegetable kingdom. These are locomotion and innervation. The *organic* functions are present in both kingdoms, with certain modifications. They are digestion, absorption, circulation, respiration, secretion, and generation.

In examining these various processes, we propose to follow the order in which they have been enumerated. We find it convenient to take the locomotive function first, because so large a proportion of the mechanical arrangements, or of the anatomy of the body, is connected with it. The transition from locomotion to innervation is easy and obvious; for the nervous system has a special connexion with the locomotive organs, in order that the influence of the will may be conveyed to them. It may be here stated, that in the animal functions the interference of volition is more frequent than in the organic ones; and that, in all, the nervous system exerts a certain control, and may influence to a great degree the performance of the functions, although some of them are essentially independent of it.

Of the minute Movements occurring in the Interior of the Body.— Of these we may distinguish three kinds: 1. Those in which particles are moved passively by forces independent of themselves. 2. Those accompanying the incessant changes of the organic elements of the tissues. 3. Those which occur in certain entire tissues on the application of an appropriate stimulus. All these movements may be called molecular, on account of the minuteness of the particles concerned in them.

1. The term *molecular motion* was used many years ago by Mr. Robert Brown, to denote a phenomenon which he had witnessed

in the particles of various organic and inorganic substances in a state of extremely minute subdivision. When these particles were suspended in water, they exhibited, under the microscope, motions, which consisted in more or less rapid oscillations and rotations of the particles themselves. He found them in the pollen of plants, in many mineral and metallic substances, in various animal matters, reduced to a subtle powder, consisting of particles that ranged in diameter between the $\frac{1}{15000}$ and $\frac{1}{30000}$ of an inch. The movements are clearly not peculiar to living or organic parts, for they occur in inanimate ones: they never occur excepting when the particles are suspended in water, or some liquid; and they are attributable to currents produced in the fluid by evaporation at its surface or edges, for they may be arrested by covering the fluid with oil, or using other means to prevent such evaporation. They are not, therefore, inherent in the particles themselves, which only obey the impulse communicated to them by the currents created in the fluid which holds them in suspension.

Certain particles, naturally very minute, which are met with in the body, exhibit motions when examined under the microscope, floating in fluid. These motions are entirely due to the same cause as would excite them in inorganic particles, namely, to currents in the fluid created by its evaporation. The minute granules, or particles of the chyle, have been found to exhibit molecular motion; and it has been ingeniously supposed, that "these motions indicate the first obvious impress of vitality which the new material has received from its association with living matter." But, before this supposition can be admitted, we require evidence to shew that these motions are inherent, and do not result from currents. The minute rod-like bodies, which form the outer coat of the retina, or Jacob's membrane, also sometimes exhibit a molecular motion, when separated and examined in water, and there seems no reason to doubt that this is due to the evaporation of the fluid in which they float.

2. *Organic Molecular Motion.*—Some of the motions, which take place within the living body, may be compared to those described by Mr. Brown, inasmuch as they are generally, if not always, due to an extraneous force acting upon the particles moved; but they differ in this respect, viz. that the producing force is developed by the processes inseparable from life. Such motions are not in general visible, yet some have been seen, which clearly indicate that forces are developed, during life, capable of producing them. The movements of particles within cells afford an example: such motions are either of a uniform rhythmical kind, or they are

apparently irregular and oscillating. Those of the former kind are familiarly known in the vegetable kingdom by the Cyclosis which takes place in the oblong cells of Chara; the granules, which may be seen in motion, are quite passive and are carried along by currents within the cell. Motions of the latter kind have been seen by Schwann among the granules contained in the cells of the germinal membrane of the hen's egg, as if occasioned by an endosmotic current through the wall of the cell. This membrane is the seat of active change, the development and growth of new cells, destined for the evolution of the textures of the embryo; and they derive their nutriment from the yolk, on the surface of which they lie. Here the contained particles are passive, and the motion in them is only the index of the currents which give rise to it. A molecular motion of the same kind may be seen in the very minute granules, which occupy the cells of the membrane of black pigment on the choroid coat of the eye. Whether this go on during life, it is, of course, impossible to say, but the conditions for its production are undoubtedly present. In the blood may be seen another example of the kind of motion under consideration. The circulation of this fluid may be readily followed in transparent parts; and certain particles, the blood-discs, which float in it in great numbers, exhibit movements which can scarcely be attributed solely to the current of the circulating fluid. It is probable that secondary currents may be established in the blood, or that attractions and repulsions may exist between the particles themselves, or between them and the walls of the blood-vessels giving rise to these motions. According to some observers, the blood-discs undergo actual changes of shape, becoming now swollen, and now flattened; and this might be attributed to the alternate predominance of endosmose or exosmose. But the statement, that they possess an inherent power of contraction of their own, stands greatly in need of confirmation.

Organic Molecular Action occurs in nearly all the internal processes. The introduction of new matter from without into the blood; the removal of effete particles by a process of absorption; the transfer of nutrient matter from the blood to supply the place of the particles thus removed; the separation of organic compounds in glands, cannot take place without a movement of molecules in the textures concerned in these processes. We are as much at liberty to infer, that these motions are produced by certain affinities of the particles of the tissues, as that chemical action is the result of affinities between certain forms of matter. These motions of the organic and inorganic elements are incessant during the ceaseless round of organizing and disorganizing actions of which every tissue is the seat, as long as it continues living. The currents alluded to in the preceding paragraph are visible indications of the presence of these organic movements.

3. The molecular movements of nerve and muscle under stimulation have been already mentioned in the preceding chapter. The capacity of exhibiting these movements exists only while the nutritive process continues to be carried on in the respective tissues — it ceases with life. It would appear that the precise chemical constitution, which is essential to its existence, is of so unstable a nature as to be constantly prone to change, and to require incessant renewal; or, it may be, that this capacity is one which is only developed during the active operation of certain chemical forces, as if it depended necessarily on certain peculiarities of the organic elements when in a nascent or changing state.

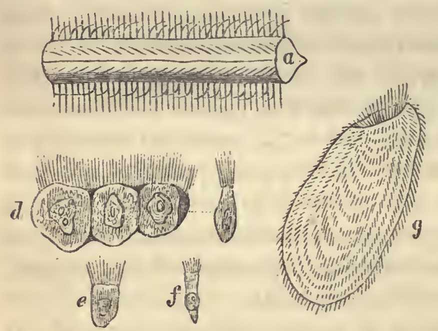
In *muscular movement* there is a visible approximation of the ultimate particles of the tissue in a determinate direction, as will be further explained in the proper place; and in this consists the whole value of muscular tissue as a part of the mechanism of the body. All those motions in the living body which are visible to the naked eye, and many of those which cannot be seen without the aid of lenses, are effected by muscular action. By it canals or tubes adapt themselves to their contents; the heart propels the vital fluid; the digestive canal transmits the ingesta from one part to another; the excretory reservoirs, or ducts, expel their contents; and lastly, by it the attitudes are maintained, and the locomotive function is performed.

Ciliary Motion.—In the same category with the molecular motions of the living body we would place that singular phenomenon, now well ascertained by multiplied observations, which is called *Ciliary motion.*

Certain surfaces, which are, in their natural and healthy state, lubricated by fluid, are covered with a multitude of hair-like processes, of extreme delicacy of structure and minuteness of size. These are called *cilia,* from *cilium,* an eye-lash. They are generally conical in shape, being attached by their bases to the epithelium that covers the surface on which they play, and tapering gradually to a point; or, as Purkinje and Valentin state, they are more or less flattened processes, of which the free extremities are rounded; and this latter form prevails in the human subject. They vary in length from the $\frac{1}{1000}$ to the $\frac{1}{12000}$ of an inch. They are disposed in rows, and are adapted in their arrangement to the shape and extent of the surface to which they belong; they adhere to the edges, or to a portion of the surface, of the particles of the epithelium, preferring the columnar variety of them.

During life, and for a certain period after death, these filaments exhibit a remarkable movement, of a fanning or lashing kind, so that each cilium bends rapidly in one direction, and returns again to the quiescent state. The motion, when viewed under a high magnifying power, is singularly beautiful, presenting an appearance somewhat resembling that of a field of corn agitated by a steady breeze. Any minute objects coming in contact with the free extremities of the cilia are hurried rapidly along in the direction of the predominant movement; one or more blood-discs, accidentally present, will sometimes pass rapidly across the field, propelled in this way, and very minute particles of powdered charcoal may be conveniently used to exhibit this phenomenon, and to indicate the direction of the movement. The action of the cilia produces a current in the surrounding fluid, the direction of which is shewn by the course which the propelled particles take.

Fig. 2.



Examples of Cilia:—*a*. Portion of a bar of the gill of the Sea-mussel, *Mytilus edulis*, shewing cilia at rest and in motion. *d*. Ciliated epithelium particles from the frog's mouth. *e*. Ciliated epithelium particle from inner surface of human membrane tympani. *f*. Ditto, ditto: from the human bronchial mucous membrane. *g*. *Leucophrys patula*, a polygastric infusory animalcule: to shew its surface covered with cilia, and the mouth surrounded by them.

An easy way to observe this phenomenon is to detach by scraping with a knife a few scales of epithelium from the back of the throat of a living frog. These, moistened with water or serum, will continue to exhibit the movement of their adherent cilia for a very considerable time, provided the piece be kept duly moistened. On one occasion we observed a piece prepared in this way exhibit motion for seventeen hours; and it would probably have continued doing so for a longer time, had not the moisture around it evaporated. However, Purkinje and Valentin have observed it to last for a much longer time than this in connexion with the body of the animal. In the turtle, after death by decapitation, they found it lasted, in the mouth, nine days; in the trachea and the lungs thirteen days; and, in the œsophagus, nineteen days. In frogs, from which the brain had been removed, it lasted from four to five days. The longest time they observed it to continue in man and mammalia was two days; but in general it did not last nearly so long. What appears to be immediately necessary to the continuation of the movement, is the integrity of the epithelial cells to which the cilia adhere; for as soon as these shrink up for want of moisture, or become physically altered by chemical reagents or by the progress of putrefaction, the cilia immediately cease to play.

From these facts we learn two important points in connexion with this phenomenon. The first is, the truly molecular character of the movement. Whatever be the immediate cause of the action of the cilia, it is evidently intimately connected with the minute epithelial particles to which they are attached; for cilia never exist in man and the higher animals without epithelial particles, and these particles have no organic connexion with the subjacent textures excepting such as may arise from simple adhesion. And, secondly, we perceive, that this movement is independent of both the vascular and the nervous systems, for it will continue to manifest itself for many hours in a single particle isolated from the rest of the system. After death, it remains longer than the contractility of muscle; a circumstance which, together with the facts just mentioned, indicates that the cilia cannot be moved by little muscles inserted into their bases, as some have supposed. And experiment also shews this independence. If the abdominal aorta be tied, the muscles of the lower extremities will be paralyzed in consequence of their being deprived of their blood; and on removing the ligature, and allowing the blood to flow, the muscles will recover themselves. But a ciliated surface is not affected at all in its movements, though the supply of blood to the subjacent tissues be completely cut off. Again, hydrocyanic acid, opium, strychnine, belladonna, substances which exert a powerful effect on the nervous system, produce no influence upon ciliary motion: in the bodies of animals killed by these poisons, the phenomenon is still conspicuous; and even the local application of them does not hinder it, provided the solutions do not injure the epithelial texture. Shocks of electricity passed through the ciliated parts, do not affect the movement. Lastly, the removal of the brain and spinal cords in frogs, by which all muscular movements are destroyed, does not stop the action of the cilia. This striking fact may likewise be adduced to disprove the supposition, that these movements result from the action of minute muscles; for, although muscles may be excited to contract without nerves, we have no instances in the higher animals in which they habitually act without the interference of the nervous system; nor is it likely that a movement existing over so extended a surface, as that by the cilia, would, if effected by muscles, be independent of nervous influence.

Alterations of temperature affect the ciliary motion, owing, doubtless, to the physical change they induce in the epithelial particles. In warm-blooded animals it ceases on a reduction of the temperature below 43° F. In cold-blooded animals, however, it continues even at 32°. In all, a very high temperature effectually puts a stop to it. It is interesting to notice, that all observers agree in stating, that blood is the best preservative of the ciliary motion, but the blood of vertebrata destroys it in the invertebrata. Bile puts a stop to it, very probably by reason of its thick and viscid nature, and not from any chemical influence.

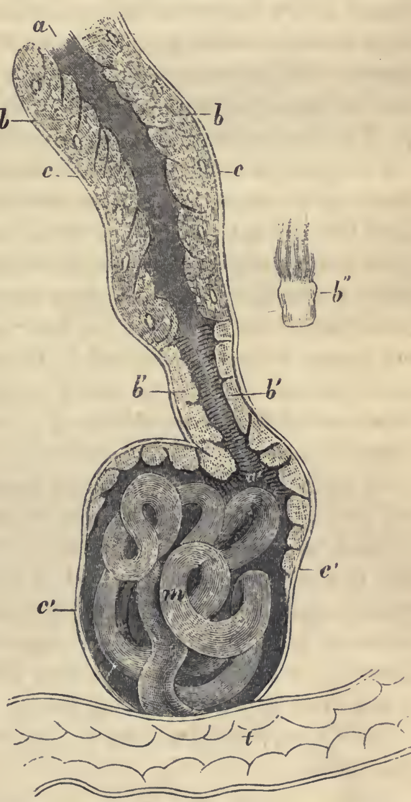
This phenomenon exists most extensively in the animal kingdom. It has been found in all the vertebrate classes; and in the invertebrata likewise, with the exception of the crustacea, arachnida, and insects. It is the agent by which the remarkable rotation of the embryo in the ova of mollusca is effected; and it occurs on the surface of the ova of polypes and sponges. The bodies of some of the infusoria are covered with cilia, which are apparently employed by them as organs of locomotion and for the prehension of food (fig. 2, *g*).

In man, the ciliary motion has been ascertained to exist on several surfaces:—1. On the surface of the ventricles of the brain and on the choroid plexuses. So delicate are the cells of epithelium here, that the slightest mechanical injury destroys them; it is, therefore, very difficult to see the movement. Valentin states, that its duration is considerable in these parts, so that it may be seen in subjects used for dissection. 2. On the mucous membrane of the nasal cavities, extending along the roof of the pharynx to its posterior wall, on a level with the atlas, on the upper and posterior part of the soft palate and in the immediate neighbourhood of the Eustachian tube, extending through the tube itself to the cavity of the tympanum. 3. On the membrane lining the sinuses of the frontal bone, the sphenoid, and the superior maxillary. 4. On the inner surface of the lacrymal sac and lacrymal canal. 5. On the membrane of the larynx, trachea, and bronchial tubes. 6. On the lining membrane of the female organs of generation. It does not exist in the vagina; but it may be traced from the lips of the os uteri, through its cavity, and through the Fallopian tubes to their fimbriated margins.

In nearly all these instances there appears to be a mechanical use for the ciliary movement, namely, to promote the expulsion of the fluid secreted by the surfaces on which the cilia exist.

Wherever the direction of the motion has been ascertained, it is that which would be favourable to such a purpose. In the bronchial tubes and trachea, the direction of the motion is towards the larynx, so that the cilia may be regarded as agents of expectoration. In the nose of the rabbit, Dr. Sharpey observed the impulse to be directed forwards, and in the maxillary sinus it appeared to pass towards the back part of the cavity, where its opening is situated. In the Fallopian tube, the direction is stated by Purkinje and Valentin to be from the fimbriated extremity towards the vagina. It seems very probable that ciliary motion exists in the kidney, at the narrow neck of each uriniferous tube, as it passes off from the capsule of the Malphigian body. This has not been actually observed in the human subject. It was discovered, and has been frequently seen in the frog,* and is shewn in the annexed drawing (fig. 3). The movement is here directed towards the uriniferous tube, and it doubtless is destined to favour the flow of the aqueous portion of the secretion from the capsule to the tube.

Fig. 3.



Uriniferous tube of Frog's kidney, arising from capsule of Malpighian body :—*a.* Cavity of the tube. *b.* Epithelium. *c.* Basement membrane. *b'.* Ciliated epithelium at the neck of the tube. *b''.* Detached ciliated particle. *c'.* Malpighian capsule. *m.* Malpighian tuft.

In the inferior animals the cilia seem to answer a similar end to that in man. They exist extensively on respiratory surfaces, and in connexion with the generative organs; and also, but to a less degree, with the organs of digestion. But in some situations, both in man and in the inferior creatures, it is difficult to determine what functions the ciliary motion can perform. Such are, in man, the ventricles of the brain; and, in the

* Bowman, Phil. Trans. 1842.

frog, the closed cavities of the pericardium and peritoneum. Here there are no excretory orifices, toward which the current might set.

What is the cause of ciliary motion? We have shewn it to be independent of the blood and of the nerves, and to resist those depressing causes which usually put a stop to the action of contractile tissue. It requires for its continuance three conditions: a perfect epithelium cell; moisture, not of too great density; and a temperature within certain limits. From Schwann's observations it appears that cells exhibit a power of endosmose; that a chemical change occurs in the fluids in contact with them; and that a movement of their internal granules may be seen under certain circumstances. If ciliated epithelium cells exert an attraction of endosmose upon the surrounding fluid, may not this physical phenomenon afford a clue to determine the cause of the movement?

A very remarkable movement is manifested by certain particles found in the secretion of the testicle, which prevails most extensively throughout the animal series, and is even found among plants. From the regularity of these movements, and their resemblance to those of minute animals, a place had been assigned by naturalists to the particles in question, in their zoological classifications, under the name "*Cercariæ seminis*," Spermatozoa, or Spermatic animalcules, and Ehrenberg refers them to the Haustellate Entozoa. These particles consist chiefly of a long filament or tail, which is sometimes swollen at one extremity, to form the body of the supposed animalcule. The motions consist in a sculling action of the tail, or a slight lateral vibration of it. In many of its conditions it closely resembles ciliary motion; and its duration after death, or after the separation of the fluid, is pretty much the same as that of the ciliary movements. The particles are extremely minute, even measured in their length; but especially so in thickness. They are, therefore, well adapted to obey those impulses which we have shewn to be capable of giving rise to molecular motions. We shall return to this curious subject again in discussing the function of generation.

On the subjects treated of in this chapter reference is made to the following sources of information:—Rob. Brown, A Brief Account of Microscopical Observations on the particles contained in the pollen of plants, and on the general existence of active molecules in organic and inorganic substances; Purkinje and Valentin, Commentatio Physiologica de phenomeno motûs vibratorii continui; article Cilia, by Dr. Sharpey, in the Cyclopædia of Anatomy and Physiology; Valentin's article Flimmer-bewegung in Wagner's Handworterbuch der Physiologie.

CHAPTER III.

LOCOMOTION.—PASSIVE AND ACTIVE ORGANS OF LOCOMOTION.—FIBROUS TISSUE, WHITE AND YELLOW.—AREOLAR TISSUE.—ADIPOSE TISSUE AND FAT.

Locomotion is that function by which an animal is able to transport itself from place to place. It is enjoyed exclusively by animals; there being nothing analogous to it in the vegetable kingdom.

But even, among animals, there are exceptions to the existence of this function. Many of them are fixed in their places throughout their lives; others enjoy the power of locomotion for a short period, but subsequently become fixed; others, again, begin life fixed to one place, and are at length set free.

The power of maintaining the body in certain positions, must be included in the faculty of locomotion, for the organs that are used for one, are also employed for the other; and, the more difficult it be to accomplish the former, the more complicated will be the mechanism of the locomotive acts. In a large quadruped,—the horse, for example,—standing is effected with a trifling expenditure of muscular force, because the animal's body is maintained on four pillars of support, which resist the attraction of gravity acting upon it. Man has to maintain the erect attitude, and to counteract by muscular action the tendency of his body to gravitate forwards. The mechanical adjustments of his frame are less favourable to preserve the standing posture than in the four-footed animal. Hence, in man, the mechanism of locomotion is more complicated, both as regards the power of preserving certain attitudes, and that of moving from one place to another.

The organs employed in locomotion are of two kinds, the *passive*, and the *active*. The former consist of all those textures which form the skeleton, and by which its segments are united. The latter are the muscles, to which the nerves convey the mandates of the will. It will be necessary to examine in detail the following textures among the passive organs of locomotion:—1. Fibrous tissue, as binding together the various segments of the skeleton, and connecting the muscles to the bones; 2. Areolar tissue, which is so extensively diffused throughout the body, at once separating and uniting neighbouring parts; 3. Cartilage, fibro-cartilage, and bone, which enter immediately into the construction of the skeleton; and, lastly, synovial and serous membranes, being peculiar arrangements of tissue admirably suited to facilitate motion.

FIBROUS TISSUE.

Under this head anatomists range two kinds of texture, resembling each other only in the fact that they present to the naked eye a fibrous aspect, as if they were compounded of a series of bundles of threads or fibres. They differ, however, very materially in colour, in physical properties, in ultimate structure: the general purposes which they serve in the animal œconomy are pretty much the same; for both are used in connexion with the skeleton, and are concerned in the mechanism of animal motion and locomotion. They are distinguished as, 1. White Fibrous Tissue; 2. Yellow Fibrous Tissue.

1. *White Fibrous Tissue.*—When a texture of great strength and flexibility, and of an unyielding nature, is required, either to bind parts of the skeleton together, to cover and protect organs of delicate texture, to unite muscles to bone, or other parts, to compress the muscles of a limb, or strengthen the walls of a cavity, we find white fibrous tissue called into requisition for these purposes. Hence we observe it to assume a great variety of forms, according to the various uses to which it is applied. It occurs, 1, as ligaments, connected with joints; 2, as tendons, connecting muscles to bones; 3, in a membranous form, covering and protecting certain organs, as the dura mater of the head and spine, the tunica albuginea of the testicle, the sclerotic coat of the eye, the fibrous pericardium, the covering of the corpora cavernosa penis, the fibrous sheaths of tendons, the periosteum of bone, the perichondrium of cartilage, the aponeuroses of the limbs, as the fascia lata, &c.

When we examine a portion of fibrous tissue taken from any of these sources, we find connected with it a greater or less quantity of areolar tissue, which adheres to its outer surface like a sheath. This is the case in all fibrous structures, except those which have a serous membrane connected with them, or those adherent to bone or cartilage. The areolar tissue sinks into the fibrous material, and mingles with its fibres: and, doubtless, it not only serves the purpose of a nidus for conducting vessels to its surface, but it accompanies them sparingly into its substance.

When the areolar tissue has been dissected off, the surface of the fibrous tissue exhibits a beautiful silvery-white aspect, and seems composed of bundles of fibres, which in some are arranged parallel to each other; in others are disposed on different planes, and interlace, or cross in different directions. On placing a very thin piece of the fibrous tissue under a high power of the microscope, we observe what may be considered the characteristic feature of this texture.

The piece under examination seems to be composed of a leash of exceedingly delicate fibrillæ, running parallel to one another, and, if not stretched, disposed to take a wavy course, like a skein of silk. But, on more accurate inspection, it is found impossible to distinguish threads of a determinate size; they seem, indeed, to be of various sizes, according to the degree of splitting to which the whole has been submitted, and many are to be seen so very minute, as at first almost to elude the eye. In other parts the mass splits up into membranous rather than filiform fragments; so that it would appear incorrect to describe this tissue as a bundle of threads. It is rather a mass, with longitudinal parallel streaks, (many of which are creasings,) and which has a tendency to slit up almost *ad infinitum* in the longitudinal direction. The correctness of this view is further shewn by the action of acid, which obliterates, for the most part, all appearance of fibrillæ, and swells it up as an entire mass.

Fig. 4.

White fibrous tissue:—*a.* Straight appearance of the tissue when stretched. *b. c. d.* Various wavy appearances which the tissue exhibits when not stretched.—Magnified 320 diameters.

Physical and vital Properties.—White fibrous tissue is *inelastic*, and, under ordinary circumstances, *inextensible;* though it does admit of being somewhat stretched by the influence of long-continued and slowly acting force, as is seen occasionally when an effusion of fluid has taken place into an articular cavity, or when a tumour has slowly grown under a fascia. Its force of cohesion is the most valuable and characteristic quality of the white fibrous tissue, and to this its various important uses are chiefly due. Mascagni calculates the force requisite to rupture the tendo Achillis as equal to 1,000 pounds' weight. Instances are constantly seen where muscles are torn, or bones fractured, while the tendons or ligaments, through which the force has acted, have escaped. Thus, the malleoli are often dragged off by twists of the foot acting on those processes of bone through the lateral ligaments of the joint. It is entirely devoid of contractility or irritability; and its sensibility is very low, so much so that tendons hanging out of a wound have been cut without the patient being aware of it.

Vessels and Nerves.— White fibrous tissue contains few vessels; they are small, and follow for the most part the course of the bundles of the tissue; they appear more numerous in the dura mater, and in periosteum, than in other parts. The presence of nerves, and their mode of subdivision, have not as yet been satisfactorily demonstrated anatomically; we infer their existence from the tissue manifesting sensibility in some forms of disease.

Chemical Composition.— The flexibility of fibrous tissue is owing to its containing a small proportion of water. A tendon, ligament, or fibrous membrane, will dry readily; it then becomes hard and rigid; it resists the putrefactive process when not kept moist, and even then putrefies less readily than the softer textures. Acetic acid causes it to swell up, instantly removes its peculiar appearance of wavy fibres, and displays some broken elongated corpuscles, which are probably the remains of the nuclei of the development-cells. Gelatine may be extracted in considerable quantity from white fibrous tissue by boiling, and it would appear to constitute its chief proximate principle.

Of the different Forms of White Fibrous Tissue.— A. *Ligaments.*— Ligaments are connected with joints. They pass in determinate directions from one bone to another, and serve to limit certain movements of the joint, while they permit others. They, therefore, constitute an extremely important part of the articular mechanism in preserving the integrity of the joint in its various movements. There are three principal kinds of articular ligaments.—1. *Funicular*, rounded cords of white fibrous tissue, of which we may give as examples the external lateral ligament of the knee-joint, the perpendicular ligament of the ankle-joint, &c.: 2. *Fascicular*, flattened bands, more or less expanded; ex. internal lateral ligament of the knee-joint, lateral ligaments of the elbow-joint, anterior and posterior ligaments of the wrist-joint, and, indeed, the great majority of ligaments in the body: 3. *Capsular;* these are barrel-shaped expansions, attached by their extremities around the margin of the articular surfaces composing the joint, and forming a complete but a loose investment to it, so that its movements are not particularly restricted in one direction more than another.

They constitute one of the anatomical characters of an enarthrodial or ball-and-socket joint, and are found in the only two perfect examples of that form of articulation, namely, the shoulder and hip joints.

B. *Tendons.*— Tendons serve to attach muscle to bone, or some other part of the sclerous system. We may enumerate three varieties of tendon, as regards form: 1. *Funicular, e.g.* long tendon of the biceps cubiti; 2. *Fascicular,* short tendon of the same muscle, and most of the tendons of the body; 3. *Aponeurotic,* tendinous expansions, sometimes of considerable extent, and very useful in protecting the walls of cavities. The tendons of the abdominal muscles afford good examples of this variety.

The tendons are for the most part implanted by separate fascicles into distinct depressions in the bones, and are also closely incorporated with the periosteum; so that in maceration, when the latter is separated, it becomes easy to remove the tendons. In some birds whose tendons are black, the periosteum is black also; and in the human subject we may often see the tendinous fibres continued on the surface of the periosteum, as a shining silvery layer, following the primitive direction of the tendinous fibres, from which they were derived; a marked example of this may be seen on the sternum, in front of which the tendinous fibres of the opposite pectoral muscles meet and decussate, and thus form the superficial layer of the periosteum covering that bone. The length of the tendons is beautifully adapted to the quantity of contractile fibre required to perform a certain movement; thus, in the biceps cubiti, were the whole length between the scapula and radius occupied by muscular fibre, there would be a great waste of that contractile tissue, as there would be much more than is wanted to produce the required motion; tendon is, therefore, made to take the place of the superfluous muscle: in this way we may explain the differences in length of the tendons even in the same limb.

C. *Membranous.*— In the form of an expanded membrane white fibrous tissue is used to cover, protect, and support various parts. Under such circumstances we often find that it not only forms an external covering to them, but that it sends in processes or septa, which separate certain subdivisions or smaller parts. Thus, the fascia lata of the thigh not only invests the muscles of the thigh, but sends in processes which pass down to the periosteum, and separate the several muscles from each other; and the dura mater of the cranium sends in processes by which certain portions of the encephalon are separated from one another.

Reparation and Reproduction.— When a solution of continuity takes place in white fibrous tissue, it readily heals by the interposition of a new substance, every way similar to the original tissue, excepting that it wants its peculiar glistening aspect, and is more bulky and transparent.*

2. *Yellow Fibrous Tissue.*— In colour, and in the possession of elasticity to a remarkable extent, this tissue differs manifestly from that last described.

Fig 5.

Yellow fibrous tissue. shewing the curly and branched disposition of its fibrillæ, their definite outline, and abrupt mode of fracture. At *e*, the structure is not disturbed, as in the rest of the specimen. — Magnified 320 diameters.

It is yellow: disposed in bundles of fibres, and covered by a thin sheath of areolar tissue, which likewise sinks in among its fibres. In man it exists in the fascicular, funicular, and membranous forms.

Under the microscope we observe it to consist of fibres, round in some, flattened in other specimens. These fibres are very variable in diameter, usually from $\frac{1}{5000}$ to $\frac{1}{10000}$ of an inch in diameter. They bifurcate, or even divide into three; and the sum of the diameters of the branches considerably exceeds the diameter of the trunk. They anastomose freely with each other. They are prone to break under manipulation, and the broken extremities are abrupt and disposed to curl up: when many of these broken ends exist together in the same piece, they give it a very peculiar and characteristic appearance.

In the human subject, we find this tissue employed in the spine, as the *ligamenta subflava,* extended between the laminæ of the vertebræ; in the larynx, forming the thyro-hyoid and crico-thyroid membranes, and the chordæ vocales; and in the trachea, forming the longitudinal or elastic bands of that tube, and of its branches. The internal lateral ligament of the lower jaw, the stylo-hyoid ligament, and the transversalis fascia of the abdomen, are also, in a great measure, composed of it. Among the lower animals it is very extensively used for mechanical purposes, of which there is a familiar instance in the *ligamentum nuchæ* of quadrupeds. Its great elasticity fits it for restoring parts after they have been moved by muscular action. Hence it is generally employed to supply an antagonist force to the muscular.

A peculiar modification of the yellow fibrous tissue composes

* We have ascertained this in the case of a divided tendo Achillis.

the proper coat of the arteries, and it will be described with the blood-vessels.

In *chemical constitution*, this tissue differs remarkably from the white fibrous tissue. It is unaffected by the weaker acids, or by boiling, and will resist putrefaction, and preserve its elasticity during a very long period. Very long boiling appears to extract from it a minute quantity of a substance allied to gelatine; but this is perhaps derived from the areolar tissue and vessels, which always penetrate sparingly among its fibres, and cannot be separated by dissection.

There appear to be no vestiges of the nuclei of cells in this tissue; at least, we have failed to detect them.

We have hitherto spoken of the two forms of fibrous tissue as they occur in isolated masses; but their distribution through the body is far more extensive than this description would imply. In a diffused form, blended with one another in very varying proportions, and each one of them presenting a variety of modifications, they compose the *areolar tissue*, which may now be conveniently considered under a separate head.

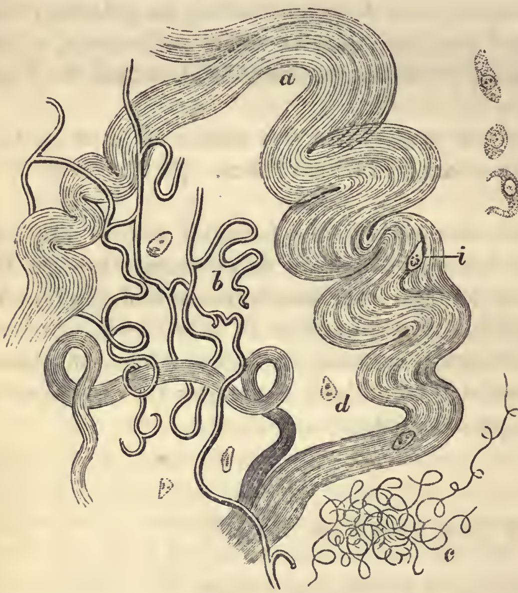
OF THE AREOLAR TISSUE.

(*Cellular or Filamentous Tissue*).

This is very widely dispersed among the other tissues of the body, and of itself constitutes a principal portion of some organs. It serves the most important purposes in the *construction* of the body, by binding together, and yet allowing movement between, its elementary parts; and it contributes largely to the formation of membranes conferring protection by their toughness, resistance, and elasticity.

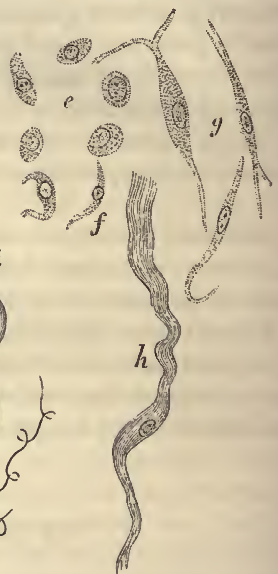
Microscopic Characters.—When a fragment of the areolar tissue from a favourable situation is examined, it presents an inextricable interlacement of tortuous and wavy threads intersecting one another in every possible direction. They are of two kinds. The first are chiefly in the form of bands of very unequal thickness, and inelastic. Numerous streaks are visible in them, not usually parallel with the border, though taking a general longitudinal direction. These streaks, like the bands themselves, have a wavy character, but they are rendered straight by being stretched. The streaks seem more the marks of a longitudinal creasing, than a true separation into threads; for it is impossible by any art to tear up the band into filaments of a determinate size, although it manifests a decided tendency to tear lengthwise. The larger of these bands are often as wide as $\frac{1}{500}$ of an inch; they branch, or unite with others, here

Fig. 6.



The two elements of Areolar tissue, in their natural relations to one another:—*a.* The white fibrous element, with cell-nuclei, *i*, sparingly visible on it. *b.* The yellow fibrous element, shewing the branching or anastomosing character of its fibrillæ. *c.* Fibrillæ of the yellow element, far finer than the rest, but having a similar curly character. *d.* Nucleolated cell-nuclei, often seen apparently loose.—From the areolar tissue under the pectoral muscle, magnified 320 diameters.

Fig. 7.



Development of the Areolar tissue (white fibrous element):—*e.* Nucleated cells, of a rounded form. *f. g. h.* The same, elongated in different degrees, and branching. At *h*, the elongated extremities have joined others, and are already assuming a distinctly fibrous character.—After Schwann.

and there. The smaller ones are often too minute to be visible, except with a good instrument. These are the *white fibrous element.*

The others are long, single, elastic, branched filaments, with a dark, decided border, and disposed to curl when not put on the stretch. These interlace with the others, but appear to have no continuity of substance with them. They are for the most part about the $\frac{1}{8000}$ of an inch in thickness; but we often see, in the same specimen, others, of much greater density. These form the *yellow fibrous element* (fig. 6).

These two tissues may be most easily discriminated by the addition of a drop of dilute acetic acid, which at once swells up the former, and renders it transparent, while it produces no change in the latter. The wavy bands of the white fibrous part, on being touched by the acid, may be seen to expand *en masse,* and not as though they consisted of a mere bundle of smaller filaments; yet there often remains in them an appearance of more or less wavy transverse lines at pretty equal distances, remotely resembling those on the fibre of striped muscle. These we are unable to explain. The acid also brings into view *corpuscles* of an oval shape, often broken into fragments, and stretching for some distance along the interior of the band. These seem to be the nuclei of the cells from which the bands have been originally produced.

In the earliest period at which the areolar tissue can be examined, Schwann has described it as consisting of nucleated particles, sending offsets on the opposite sides, and connecting themselves with others in the vicinity. The threads thus formed are at first homogeneous; the longitudinal streaks and the wavy character appear subsequently (fig. 7). His description is drawn from the white fibrous element; but it may be extended to the yellow also.

We have observed frequently among the threads of areolar tissue taken from adult subjects a number of corpuscles (fig. 6, *d*), either isolated, or having very delicate prolongations among the neighbouring threads. These seem with great probability to be either advancing or receding stages of the tissue.

It is not known whether the ultimate elements of the areolar tissue have any immediate attachment or union with the other tissues, among which they lie, or whether they merely enclose them by the complexity of their web.

By the endless crossing and twining of these microscopic filaments, and of fasciculi of them, among one another, a web of amazing intricacy results, of which the interstices are most irregular in size and shape, and all necessarily communicate with one another.

This is well seen by forcibly filling the tissue with air or water in any region. In the living body this is very obvious in anasarca, and in traumatic emphysema, as in the remarkable case related by Dr. W. Hunter in his celebrated paper (Med. Obs. and Inquir. vol. ii. p. 17), where the whole body was blown up so tensely as to resemble a drum.

The interstices are not cavities possessed of definite limits, because they are open on all sides, and ultimately constituted out of a mass of tangled threads. The application of the term, *cell,* to them, is therefore inappropriate; and it cannot be wondered at, that it should have led to much confusion. In certain situations, how-

Fig. 8.

Portion of Areolar tissue, inflated and dried, shewing the general character of its larger meshes. Each lamina and filament here represented contains numerous smaller ones matted together by the mode of preparation.—Magnified twenty diameters.

ever, where this tissue is in great abundance, and where it first attracted attention at the time when elementary tissues began to be separately studied, the meshes thus formed are disposed so as to constitute secondary cavities, having a somewhat determinate shape and size, and which are visible to the naked eye. These generally contain fat, and may be admirably studied in most parts of the subcutaneous tissue. They are better deserving the name of cells than the interstices formed by the first interlacement of the elementary filaments. But they communicate freely, as the smaller interstices do, their walls being everywhere cribriform, and capable of giving passage to air or fluids.

The areolar tissue is one of the most extensively diffused of all the elements of organization, and its chief purpose seems to be that of connecting together other tissues in such a way as to permit a greater or less freedom of motion between them. To do this, it is placed in their interstices, and is more or less lax, more or less abundant, according to the particular exigency of the part. It is by means of this tissue, as well as by the complexity of its own web, that almost every part of the vascular system is fixed in its position, and allowed to undergo the movements impressed upon it by the circulative powers. Even the capillaries supplying this system itself are for the most part brought to it, and enveloped, by this tissue.

So true and comprehensive is this description of the association of the areolar tissue with the vascular, that it would be difficult to point out a single instance in which one office of the former is not to envelope and protect the latter. But the statements that have been made of its universal presence have no good evidence in their favour. In the compacter parts of bone, in teeth, and in cartilage, it is certainly not present; and, indeed, it could serve no purpose in those structures. In the substance of the brain, also, it does not exist, excepting around the vessels two or three removes from the capillaries.

In the muscles it connects the elementary fibres to one another, and preserves them from undue separation during contraction; but even here it is bound within the same limits as the capillaries, not penetrating the sarcolemma to touch the contractile element within. It enters the muscles abundantly along with their vessels and nerves. It is remarkable, however, that the central organ of the circulation, like the central organ of the nervous system, contains this tissue in very small proportion; one reason of which seems to be, that its fibres differ from the parallel fibres of other muscles, by twining among one another, and thus are enabled to dispense with an extraneous bond of connexion.

Besides penetrating between the fibres of the muscles, whose minute parts are in continual movement upon one another during contraction, it generally invests their exterior, in a profusion proportioned to the extent to which these organs move as a whole upon neighbouring parts, of which the best examples may be seen, between the great muscles of the extremities; between these and their enveloping fasciæ (not their fasciæ of origin); under the occipito-frontalis muscle and its tendon; and in the upper eyelids.

The areolar tissue is also present in immense quantities under the skin of most parts of the body, and especially where great mobility of the integument is required, either as a protection to deeper organs against external violence, or to facilitate the various movements of the frame. Such are the regions of the abdomen, and of several of the articulations, and the eyelids.

Around internal organs which change their form, size, or position in the routine of their functions, and which are wholly or partially without a free surface, as the pharynx, œsophagus, lumbar colon, bladder, &c., this tissue is abundant, and its filaments so long, tortuous, and laxly interwoven, as to admit of a ready and extensive motion on the neighbouring viscera.

This tissue likewise forms a layer lying under the mucous and the serous membranes in almost every situation, though presenting great variations of quantity and denseness: it renders the movements of such parts easy. It also closely invests the exterior of every gland and parenchymatous organ, and enters more or less abundantly into its inner recesses, along with its vessels, nerves, and absorbents: but there is no doubt that it has been supposed to have a much greater share in the formation of this numerous class of organs than an ultimate anatomical analysis of them, conducted with careful precision, will at all warrant. In all these cases it is a more or less copious attendant on the vessels; but wherever, either from the intricacy of the interlacement of the capillaries with the other *essential* elements of the particular organ, or the greater strength of these elements themselves, the firm contexture of the whole is provided for, while little or no motion is required between its parts, this interstitial filamentary tissue will be found to be confined to the larger blood-vessels, and to the *surface* of the natural subdivisions of the organ.

For the present, it may be sufficient to illustrate this remark by contrasting two important glands, in reference to this point. The *liver* is well screened from injury by its position; it is liable to no change of bulk; it consists throughout of a continuous and close network of capillaries, the interstices of which are filled by the nucleated secretion-particles. The lobules resulting from the distribution of the vessels and ducts blend together at numerous points, and have no motion on one another. Here the areolar tissue is in very small quantity, and is limited to the ramifications of the vessels and ducts. The *mamma*, on the other hand, is, by its situation, peculiarly obnoxious to external injury. It is broken up into numerous subdivisions, which move with the utmost freedom on one another, and it is, moreover, liable to temporary augmentations of bulk. In this important gland not only is there a common investment of peculiar density, but an extraordinary abundance of areolar tissue disseminated throughout its interior.

Thus, this tissue, so widely spread throughout the body, whether it serve the purpose of an investment to large segments or masses, under the form of a membrane, strengthening and protecting them, and escorting their vessels and other components into and from their substance (atmospheric), or as a web of union between the simplest elements of their organization (parenchymal), is to be regarded as rather taking a subordinate or ministering share in the constitution of the frame, than as being of primary importance in itself.

It is a cement that allows of separation between what it binds together; and it accomplishes this double purpose in a manner suited to the necessities of diverse parts, by a variety so simple in the number, intricacy, and closeness of its threads, as to be worthy of the highest admiration, while it is wholly inimitable by art.

Where great elasticity is required, the yellow element preponderates; while the white fibrous element abounds in parts demanding tenacity and power of resistance. In all cases the openness of the network is proportioned to the extent of mobility required. Where the meshes are small, the threads composing them branch and anastomose with one another with much greater frequency. The texture of the cutis affords the most characteristic example of this condition.

Physical Properties.—These have only been studied hitherto in those situations where the tissue exists in great abundance, as in the subcutaneous fascia, the sheaths of muscles, &c. It has here a whitish hue, especially when steeped in water. It is extensible in all directions, and is very elastic, returning to its original disposition after stretching. It possesses no contractility beyond that attributable to the vessels which are everywhere found in connexion with it, and in such situations in great profusion. Its sensibility is usually stated to be low; but it may be doubted whether the nerves can in any case be said to be distributed to this tissue, which has been already shewn to be an appendage and protector to these and other organs. Its asserted powers of absorption and secretion appertain to the capillary blood-vessels, rather than to the threads of the areolar tissue.

This tissue, like all other soft solids, contains a large quantity of water. This keeps the filaments moist, without being so abundant as to be free in their interstices. A morbid increase of this fluid in the subcutaneous areolar tissue occasions the condition called anasarca, and which may be known by the skin pitting under the pressure of the finger.

When dried, out of the body, areolar tissue becomes hard and transparent, but resumes its former state if moistened. It undergoes the putrefactive process slowly. It is one of that class of tissues which yields gelatine by boiling, the gelatine being derived from the white fibrous element only.

The great value of areolar tissue, in facilitating the motion of parts between which it is situate, is shewn by the effects of inflammation, or other diseases which injure its physical properties. It is well known, that, when the subcutaneous tissue is the seat of phlegmonous inflammation, the movements of the part affected are stiff and painful, or altogether impeded, because the subjacent muscles cannot move freely, by reason of the loss of elasticity in the areolar tissue. When this tissue becomes indurated by an effusion of coagulable material, the movements of the diseased limb are similarly impaired.

OF THE ADIPOSE TISSUE, AND OF FAT.

This tissue has no alliance either of structure or function with the areolar tissue; it is, however, usually deposited in connexion with that tissue, and therefore we find it convenient to notice it here. Malpighi, W. Hunter, Monro, and, more recently, other distinguished anatomists, pointed out the distinctness of these two tissues; but such has been the influence of the term *cellular*, applied to both, that they are still usually classed together. Now, however, that microscopes, on which reliance can be placed, declare their totally distinct nature, it is full time that they be treated of as altogether distinct and independent tissues.

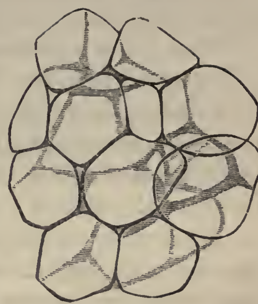
A common use of the adipose tissue being to occupy spaces of various dimensions left in the interstices between organs, and thus to facilitate motion and contribute to symmetry, it is very commonly closely associated with the areolar tissue; but the connexion is not an essential one. In the cancelli of bones there is a large deposit of fat, but none of this filamentary tissue; and in numerous situations, as the eyelids, beneath the epicranial aponeurosis, between the rectum and bladder, under the mucous membranes, and in the whole of the cutis, the areolar tissue exists without being ever accompanied by fat. Nevertheless, their apparent admixture in many situations has given rise to the term "*adipose cellular tissue,*" applied to the two combined, as distinguished from that areolar tissue which contains no fat. This term should be discarded, as leading to much misconception.

A distinction is to be drawn between fat and the adipose tissue. The *tissue* is a membrane of extreme tenuity, in the form of closed cells or vesicles; the *fat* is the material contained within them.

The *Membrane of the Adipose Vesicle* does not exceed the $\frac{1}{20000}$ of an inch in thickness, and is quite transparent. It is moistened by watery fluid, for which, as Mr. Paget has suggested, it has a greater attraction than for the fat it contains. It is perfectly homogeneous, having no appearance of compound structure, and consequently belongs to the class of simple or elementary membranes. Each vesicle is a perfect organ in itself; is from the $\frac{1}{300}$ to the $\frac{1}{800}$ of an inch in diameter, when fully developed; and is supplied on its exterior with capillary blood-vessels, having a special disposition.

The fat vesicles are usually deposited in great numbers together, and they then become flattened on their contiguous aspects, and assume a polyhedral figure more or less regular (fig. 9). But, if isolated, their form is rounded, as may be seen in eminent beauty in the double series of them which frequently accompanies the minute vessels traversing membranous expansions of the areolar tissue, and other lamellar structures, as the mesentery of small animals. The vessels are thus attended by fat vesicles, for the manifest purpose of protection from the pressure to which they would be exposed in their open course, and they throw around each vesicle a capillary loop.

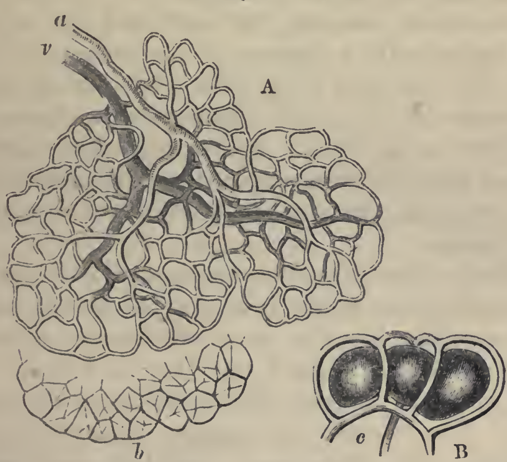
Fig. 9.



Fat vesicles, assuming the polyhedral form from pressure against one another. The capillary vessels are not represented.—From the omentum: magnified about 300 diameters.

Where the fat is in considerable quantity, it is commonly subdivided into a number of small fragments or lobules, fitted accurately to one another and invested with areolar tissue, for the purpose, chiefly, of permitting motion between the parts of the mass, but, also, for the convenience of the distribution of its blood-vessels.

Fig. 10.



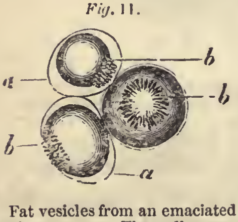
Blood-vessels of Fat: A. Minute flattened fat-lobule, in which the vessels only are represented. *a.* The Terminal Artery. *v.* The Primitive vein. *b.* The fat-vesicles of one border of the lobule, separately represented. Magnified 100 diameters.—B. *Plan* of the arrangement of the capillaries on the exterior of the vesicles: more highly magnified.

The blood-vessels enter the chinks between the lobules (fig. 10, A. B.), and soon distribute themselves through their interior, under the form of a solid capillary network, whose vessels occupy the angles formed by the contiguous sides of the vesicles, and anastomose with one another at the points where these angles meet. This is one of those situations where the capillary vessels can be most unequivocally proved to possess distinct membranous parietes.

Fat.—Fat is a white or yellow unctuous substance, unorganized, and secreted into the interior of the adipose vesicles. Chemists have distinguished in it two solid proximate principles, *stearine* and *margarine*, combined with a fluid one, or oil, *elaine;* on the relative proportions of which the principal of the numerous modifications of its external qualities would seem to depend. These principles may be obtained by different means. Boiling alcohol dissolves both, but on cooling deposits the stearine in snow-white flakes; and the elaine may be set free by the addition of water, for which the alcohol has a superior affinity. Or, the elaine may be separated by pressure. Stearine preserves its solidity at a temperature of 167° Fahr., and elaine remains fluid at 63° or 65° F. Margarine exists along with stearine in most fats, and may be separated from it by ether, which dissolves margarine, but not stearine; it is said to exist alone in human fat, which is therefore destitute of stearine. These proximate elements of fat are regarded by modern chemists as natural compounds of certain organic acids with an organic base, to which the name of *glycerine* has been given, from its sweet taste. The acids are, the *stearic*, *margaric*, and *elaic;* and the proximate principles are, respectively, a stearate, a margarate, and an elaate of glycerine. By boiling oil or fat with a solution of caustic alkali, the acids unite with the potash, forming soap, and the glycerine remains dissolved in the liquid. By evaporating this liquid (in which any excess of alkali had been previously neutralized by tartaric acid) to a thick syrup, the glycerine may be obtained from it in solution by strong alcohol.

We may often detect a spontaneous separation of these two proximate principles within the fat vesicle of the human subject. The solid portion collects in a spot on the inner surface of the cell-membrane, and looks like a small star (fig. 11, *b. b. b*). The elaine occupies the remainder of the vesicle, except when the quantity of fat in the cell is smaller than usual; in which case we may often discern a little aqueous fluid between the elaine and the cell-membrane on the side farthest from the star (fig. 11, *a. a.*); a condition, by the way, which is very favourable for the observation of this membrane itself.

Fig. 11.



Fat vesicles from an emaciated subject:—*a. a.* The cell-membrane. *b. b. b.* The solid portion collected as a star-like mass, with the elaine in connexion with it, but not filling the cell.

The softer kinds of fat were denominated by the older anatomists *pinguedo*, lard; and the more solid *sebum* or *sevum* suet, tallow. Hunter distinguishes four varieties as to fluidity; oil, lard, tallow, and spermaceti. The elaine of human fat retains its fluidity at 40° F. Lard melts at 86° F.; tallow at 104° F. Spermaceti is fluid in a heat above 115° F., and solid at 112°. Oil is elaine with little or no stearine, as the neat's foot oil, obtained from the bones of the ox. In lard, the stearine is in abundance, but the elaine slightly predominates. In tallow and spermaceti there is a predominance of stearine.

Ultimate Analysis of Fat.—Human fat, according to Chevreul, consists of

Hydrogen	11·416
Carbon	79·000
Oxygen	9·584
	100·000

Distribution.—The adipose tissue is found very extensively in the animal kingdom. It is found in larvæ as well as in the perfect insect: also in the mollusca. It prevails in all the tribes of the vertebrata. In fish it occurs throughout the body; but in some, as the cod, whiting, haddock, and all of the ray kind, according to Hunter, it is only met with in the liver. In reptiles it exists chiefly in the abdomen. In the frog, toad, &c. it is found in the form of long appendages, like the appendices epiploicæ, situated on each side of the spine. In birds, it exists chiefly between the peritoneum and abdominal muscles; but there is also a considerable deposit in the bones of the legs, feet, last bones of the wings, and of the tail, especially of the swimming tribes, the oily principle being more abundant than in mammals. In mammalia it is very generally diffused. This class, as a whole, has the greatest quantity under the skin, and about certain of the abdominal viscera; but the hare forms a remarkable exception, it being sometimes difficult to find a particle in its whole body. It usually abounds most in the beginning of winter; and this is especially the case with the hog, and with hybernating animals, which, during their dormant state, absorb it into the system.

It is ordinarily accumulated in large masses about the kidneys, more particularly in ruminants, where it furnishes the best example of that variety of it termed suet.

Among mankind many remarkable varieties exist in regard to this tissue. Thus, in general, women are fatter than men. The healthy human fœtus, after the middle of the period of gestation, accumulates fat in considerable quantities: towards middle age, there is a similar disposition, which has not escaped ordinary observation, "Fat, fair, and forty:" in old age and decrepitude, the adipose deposit greatly diminishes.

Differences are also constantly seen in individuals, which can be referred only to an original constitutional bent. Thus young children are occasionally so overloaded with this tissue as to be unable to follow their sports; and it is not uncommon for a similar tendency to manifest itself towards the adult period, particularly in girls. In elderly persons, fat is especially prone to be accumulated over the abdomen, and between the layers of the epiploon and mesentery. Instances where it attains the thickness of three or four inches under the skin of the belly are not unfrequent in corpulent persons. A similar abundance occasions the "double chin."

It is perhaps possible for the body to grow so egregiously fat as to become lighter than water; but whether implicit faith is to be placed in the story of the Italian priest Paolo Moccia, who weighed thirty pounds less than his bulk of water, and therefore could not sink in that fluid, we do not pretend to decide. The excessive deposit of this substance constitutes a disease, which has been not very correctly called polysarcia. John Bull is celebrated for his pronenesss to accumulate fat: M. Blainville remarks, with *naïveté,* "We have seen many individuals of the English nation whom *embonpoint* had rendered almost monstrous; and I remember among others, a man exhibited at the Palais Royal who weighed five hundred pounds. He was literally as broad as he was long."

Among the Hottentot women, the fat is apt to gather in the buttocks, and is considered a prominent mark of beauty; but this does not usually occur till after the first pregnancy. A somewhat analogous formation exists in a variety of sheep,* reared by the pastoral tribes of Asia, in which a large mass of fat covers the buttocks and takes the place of the tail, appearing when viewed from behind as a double hemisphere, in the notch of which the coccyx is buried, but is just perceptible to the touch. These protuberances, when very large, fluctuate from side to side, and sometimes attain the weight of thirty or forty pounds.

The quantity of fat in a moderately fat man is estimated by Béclard at about the twentieth of the weight of the body.

Fat is found in the following situations in the human body: in the orbits, in the cheeks, the palms of the hands and soles of the feet, at the flexures of the joints, and between the folds of the synovial membranes of joints, around the kidneys, in the mesentery

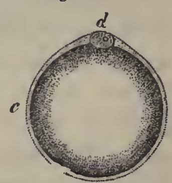
* *Ovis steatopyga,* fat-buttocked sheep. Pallas.

and omentum, in the appendices epiploicæ, on the heart, in the subcutaneous layer of areolar tissue, but especially that of the abdomen, and of the mammary region, and in the cancelli and canals of the bones forming the medulla. It never occurs in the areolar tissue of the scrotum and penis, or of the nymphæ, nor in that between the rectum and bladder, nor along the median line beneath the skin, nor in sundry other situations.

Fat is found in the liver, and in the brain and nerves, and occasionally in other organs. In these organs it is not enclosed in vesicles of adipose membrane, but in the elementary parts of the tissues themselves, as in the epithelium cells of the liver, and in the tubes and globules of the nervous substance.

Development of Adipose Tissue.— The vesicles of the adipose tissue are originally furnished with nuclei, with a central granule or nucleolus. The nucleus is situated on the inner surface of the cell-membrane, or, if this be thick, in its substance. The nucleus is speedily absorbed, and never afterwards appears. Thus it is probable that the original development-cell assumes a permanent form in the adipose vesicle.

Fig. 12.



A fat-cell, to shew the nucleus; from Schwann:—*c.* The adipose membrane. *d.* The nucleus.

Formation of Fat.— Many facts prove that the elements of fat are derived from the blood. All the most recent analyses of that fluid assign to it a certain proportion of both the crystallizable and the oily portion of the fat; according to Lecanu, about four parts in a thousand. In some instances, the fatty matter accumulates in the blood; cases of which have been recorded by Morgagni, Hewson, Marcet, Traill, and Babington. In such cases the serum is opaque and nearly as white as milk, and, on standing a short time, a film forms on the surface like cream. On the addition of ether, the creamy pellicle is dissolved, and the serum loses its opacity. M. Blainville relates, that, in dissecting the last elephant that died at the Jardin des Plantes, he happened to wound the jugular vein, and the next morning he found that the stream of blood, which flowed from the vein, had deposited on each side a considerable quantity of a fine fatty matter, which on analysis he found to have exactly the composition of ordinary fat.

From what source is this fatty material furnished to the blood? From fatty matters introduced into the system in the food, whether in animal or vegetable substances; probably, also, from those parts of the food which, in composition, resemble fat most nearly, such as the non-nitrogenised articles of diet, starch, gum, sugar, alcohol, beer, &c. Liebig states, that, by the separation of a small proportion of oxygen, any of these substances will present a composition similar to that of fat, and that an equivalent of starch may be changed into one of fat, by giving up one equivalent of carbonic acid, and seven equivalents of oxygen.

If, then, the system be imperfectly supplied with oxygen, while organic compounds containing carbon are furnished to it in considerable quantity, the most favourable conditions will exist for the development of fat. The oxygen required will be abstracted from the carbonised food, which, by that diminution of oxygen, will be changed into a fat. On the other hand, exercise and labour, which increase the supply of oxygen, diminish or prevent the formation of fat. "The production of fat," says Liebig, "is always a consequence of a deficient supply of oxygen, for oxygen is absolutely indispensable for the dissipation of the excess of carbon in the food. This excess of carbon, deposited in the form of fat, is never seen in the Bedouin or in the Arab of the Desert, who exhibits with pride to the traveller his lean, muscular, sinewy limbs altogether free from fat: but in prisons and jails it appears as a puffiness in the inmates, fed, as they are, on a poor and scanty diet; it appears in the sedentary females of oriental countries; and, finally, it is produced under the well-known conditions of the fattening of domestic animals.*

A good illustration of these views is afforded by the carnivorous animals. In the wild state, living entirely on azotised food, and enjoying abundance of air and exercise, they are lean; but, when domesticated, living on a mixed diet, devouring a highly carbonaceous food, taking little exercise, and being imperfectly supplied with oxygen, they grow fat.

In animals that hybernate, fat is deposited in enormous quantity just prior to the hybernating period, and during that time it gradually disappears, supplying nutriment to the system, and carbon for the respiratory process. These facts were clearly ascertained in hedgehogs, by the celebrated Dr. Jenner.

Liebig supposes that the formation of fat is attended with the development of heat, for the oxygen disengaged in this process unites with carbon derived from the same or a different source, and an amount of heat is generated proportionate to the quantity of carbonic acid thus formed. But it may be fairly questioned whether the temperature of the body is thereby elevated, since the

* Liebig's Organic Chemistry of Physiology.

separation of the oxygen would be doubtless attended by a degree of cooling sufficient to neutralize the heat developed in the formation of carbonic acid.

Lastly, fat, being a bad conductor of heat, is useful for retaining it in the bodies of animals. Hence those animals that have little hair on their skins, have the greatest quantity of subcutaneous fat. This is remarkably the case in the seal tribe, which has a large quantity of fat between the skin and its muscle, and is almost devoid of cutaneous covering; and, in man, the subcutaneous fat, which is so generally met with, even in apparently lean subjects, is doubtless a protection against cold.

The following works may be consulted on the subjects discussed in this chapter:—The treatise on General Anatomy by Bichat, Béclard, Craigie, and Henle; Hildebrandt's Anatomy, by Weber; Blainville, Leçons de Physiologie; Liebig's Organic Chemistry; Hunter's remarks on Fat, in the Catalogue of the Hunterian Museum, vol. iii. p. 2.

CHAPTER IV.

PASSIVE ORGANS OF LOCOMOTION, CONTINUED.—OF CARTILAGE AND FIBRO-CARTILAGE.

Cartilage is extensively used in the animal frame, and is one of the simplest of the textures. Like the adipose tissue, it approaches very closely in its intimate structure to the cellular tissue of vegetables.

In the development of the embryo, it is one of the first tissues to appear as a distinct structure, and it constitutes the internal skeleton in its earliest condition in the animal scale. The rudimentary skeleton of the cephalopoda consists of it; and in one class of fishes (hence termed cartilaginous, as the shark, ray, lamprey) the skeleton is entirely composed of it.

In man, and the higher animals, cartilage is employed temporarily, as a nidus for bone, in the early stages of life, and is then called *temporary* cartilage. This, at a certain period, begins to ossify, and finally disappears by being converted into bone. At one time, the greatest part, not the whole, of the skeleton is cartilaginous; and for a considerable period after birth the extremities of the long bones are chiefly composed of cartilage, and the larger processes are connected to the shaft of the bone by this substance.

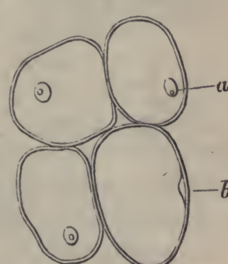
For other purposes, however, a cartilage is employed which is not prone to ossify, viz. *permanent* cartilage, and this is used either in joints (*articular* cartilage), or in the walls of cavities (*membraniform* cartilage). The articular variety is either disposed as a thin layer between two articular surfaces, and equally adherent to both, as in the synarthrodial joints (the cranial sutures, the sacro-iliac symphyses, &c.); or it forms an encrustation upon the articular ends of the bones entering into the composition of diarthrodial joints; thus, the extremities of the femur, tibia, the arm-bones, &c. are all coated with a layer of cartilage, moulded to the shape of the articular surfaces. The membraniform cartilages are not employed in connection with the locomotive mechanism, but serve to guard the orifices of canals or passages, or to form tubes, that require to be kept permanently open; the elasticity of the material effecting this without the expenditure of any vital force. Thus we find this variety of cartilage in the external ear, in the Eustachian tube, in the nostrils and eyelids, and in the larynx, trachea, and bronchial ramifications.

Physical Characters.—Cartilage, in colour, varies from an azure, or pearly white, to a whitish yellow. The temporary and articular varieties present the former colour; the membraniform, for the most part, the latter.

Elasticity, flexibility, and considerable cohesive power, are the chief physical properties of this texture; and in these qualities, and especially in the first, consists its great value, both in contributing to the perfection of the locomotive apparatus, and in its adaptation to other purposes. Cartilage is not brittle; a thin piece may be broken across by being suddenly bent at a very acute angle; but, in general, cartilage will bend easily without the occurrence of fracture, and will speedily resume its former direction on the bending force being removed.

Structure.—The simplest kind of cartilage consists merely of nucleated cells, and exceedingly resembles the cellular tissue of plants. The cells are very large, roundish or ovoidal, and more or less flattened by their mutual contact. Each has a diminutive transparent nucleus attached to the inner surface of the cell-membrane, and containing within it a minute granule, or nucleolus. We have also met with other transparent globules, of variable size and extreme delicacy, within the cells. Some white fibrous tissue usually encloses the mass of cells, and penetrates to a certain distance among the more superficial of them, which are smaller and more densely packed than the rest.

Fig. 13.



Four nucleated cells from the Chorda Dorsalis of the Lamprey; —*a.* Nucleus, with nucleolus. *b.* Another, seen in profile.

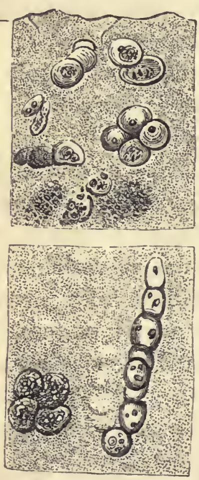
This kind of cartilage is found in the chorda dorsalis, or rudimentary spinal column of the early embryo: it also exists in the permanent chorda dorsalis of the cartilaginous fishes, and may be well seen in a thin piece of that structure from the lamprey (fig. 13).

But, in other kinds of cartilage, the cells are imbedded in an *intercellular* substance, or matrix, more or less abundant in the different kinds, and presenting certain varieties of appearance. In all, it is possible to see that the cells have a proper membrane of their own, and are not mere excavations in the intercellular substance; this may often be determined at a broken edge, the cell-membrane projecting: but it is not easy to extract a cell entire, apparently on account of the delicacy of its texture, and the density of the surrounding mass.

In *temporary* cartilage the cells are very numerous, and situated at nearly equal distances apart in the intercellular substance, which is not abundant. The cells vary in shape and size, but most are round or oval. Their nuclei are for the most part minutely granular; the granules being, in some specimens, at a distance from one another. When ossification begins, the cells, which hitherto were scattered without definite arrangement, become disposed in clusters, or rows, the ends of which are directed towards the ossifying part. These and other changes will be described in the chapter on bone.

In *articular* cartilage the cells are oval or roundish, often disposed in small sets of 2, 3, or 4, irregularly disseminated through a nearly homogeneous matrix, which is more abundant than in the last-named variety; fig. 14, A. The cells measure from $\frac{1}{1300}$ to $\frac{1}{900}$ of an inch. The nuclei are for the most part small. In the interior part of the cartilages of encrustation we usually find the cells assuming more or less of a linear direction, and pointing towards the surface; fig. 14, B. This arrangement is probably connected with a corresponding peculiarity of texture of the intercellular substance, but which it is more difficult to distinguish; for these specimens have a disposition to fracture in a regular manner along planes vertical to the surface, and the broken surface is striated in the same direction.

Fig. 14.



Articular cartilage, from the head of the Humerus:—Vertical sections: A. Section close to the surface, *a*. B. Section far in the interior.—Magnified 320 diameters.

Near its deep or attached surface, articular cartilage blends gradually with the bone it invests. The cells in the neighbourhood, as well as their nuclei, are surrounded with a sprinkling of fine opaque granules, which seem to be a rudimentary deposit of bone. The true bone dips unevenly into the substance of the cartilage.

A pavement of nucleated epithelial particles has been described by Henle to exist on the free surface of articular cartilage. In the fœtus this may be readily seen; but in the adult we have often failed to detect it, even in perfectly fresh specimens, and notwithstanding great care. An irregularity of surface, like that represented in fig. 14, *a*, often exists, and seems to shew that this covering ceases when the part becomes subject to friction and pressure. Cells, too, are often seen close to this surface, and even partly projecting from it; appearances indicative of attrition.

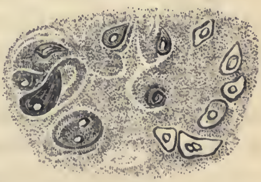
In the *cartilages of the ribs*, which occupy an intermediate place between the articular and membraniform varieties, the cells are larger than in any other cartilage in the body, being from $\frac{1}{650}$ to $\frac{1}{430}$ of an inch in diameter. Many of them contain two or more nuclei, which are clear and transparent; and some seem to contain a few oil-globules, a condition occasionally met with in other varieties. The cells often affect a linear arrangement. The rows of them are turned in all directions, and have the appearance of having been formed by the division of one cell, and the separation of its parts from each other. It is probable that the splitting of the nucleus may be the first step in this process, as, for example, in fig. 15, *a*.

Fig. 15.

Cartilage of the Ribs. Section shewing the cells, their nuclei and nucleoli. The transparent spaces result from the removal of the cells by the knife, their cavities remaining.—Magnified 320 diameters.

The intercellular substance is very abundant in these cartilages; and though it usually presents, on a section, a very finely mottled aspect, such as is very correctly pourtrayed in the figure, yet we may often discern in it a most distinctly fibrous structure, in which the fibres are parallel, and which is most evident in the aged. Perhaps it would be most correct to say that these fibres are only formed by an artificial disintegration, for they are aggregated into a solid mass in the unmutilated structure. They have very little resemblance to the white fibrous tissue. It is not known whether they take any constant direction.

Fig. 16.



Thyroid Cartilage:—Thin section. —Magnified 320 diameters.

In the true *membraniform* cartilages, the cells are very numerous in proportion to the surrounding substance, which is consequently in small quantity. This intercellular matrix is very distinctly fibrous towards the exterior of these cartilages, and often in their interior, but with considerable variety. The thyroid and cricoid cartilages, and the rings of the trachea, seem chiefly composed of clearly defined and roundish nucleated cells, huddled together, as it were, in a promiscuous manner, fig. 16. In specimens from persons of adult age, the cells have frequently a fine granular opaque matter sprinkled on their exterior; and these, in older subjects, are seen to have become minute centres of a spurious ossification.

In the *cartilage of the ear* the cells are small, and very close to each other; in shape they are very uniform, and vary in size from $\frac{1}{1300}$ to $\frac{1}{900}$ of an inch. A piece of this cartilage, when examined by a high power, has very much the appearance of a sieve; the holes of which are occupied by nuclei and their nucleoli. The intercellular substance is not exactly white fibrous tissue; but so nearly resembles it, especially towards the surface, as to make this form of cartilage approach fibro-cartilage more nearly than does any other.

The membraniform cartilages are invested by a layer of white fibrous tissue, containing blood-vessels, and called the *perichondrium.* Its fibres are densely interwoven in all directions, and adhere intimately to the intercellular substance of the cartilage. This investment corresponds with the periosteum of bone, and in the temporary cartilages is indeed the very same structure. It is a nidus for the nutrient vessels of cartilage, and often serves to give attachment to muscles. It is best examined on the cartilages of the ribs. Its great toughness is sometimes well displayed in fractures of these cartilages, where the perichondrium remains untorn between the fragments.

The articular cartilages, which have no perichondrium, are supported and supplied with blood by the bone to which they are adapted, and by the synovial membrane, which always passes for at least some little distance over their free surface.

Vessels of Cartilage.—Speaking in general terms, cartilage may be styled a non-vascular substance, for considerable masses of all its varieties exist, unpenetrated by a single vessel. The term *non-vascular,* however, it is important to observe, is to be understood in a relative sense. All tissues deriving their nutriment from blood-vessels, are, in fact, if traced up to their microscopic elements, on the outside of the channels through which the blood flows. If the quantity of vessels be large in proportion to the tissue, or if the two are mingled in an intimate manner, we term the part very vascular. If, on the other hand, there be a considerable mass of tissue, among the elementary parts of which no vessels penetrate, it is styled non-vascular. This word is not used in an absolute sense: for, if so, used, it would apply equally to all tissues, except the lining membrane of the vascular system itself, which is probably nourished by the blood immediately in contact with it.

Returning from this digression, we remark, that temporary cartilage, when in small mass, is not permeated by vessels; but that, when more than about an eighth of an inch thick, it contains canals in its interior, for the transmission of vessels. These canals are somewhat tortuous, and contain a delicate extension of the perichondrium. They may be regarded as so many involutions of the outer surface of the cartilage.

The same description will apply to the various membraniform cartilages, with this difference, that their blood-vessels are less numerous. In those which are thin, no vascular canals are to be found; but where there is much substance, as in the costal cartilages, they are easily detected.

Nothing is more certain than that articular cartilage, in man, is not penetrated by blood-vessels. Coloured fluids injected into the vessels cannot be made to enter it, but are seen to turn back, on reaching it, into the tissue which conveyed them to it. But we possess a more certain test than this, in the examination of thin slices of the tissue under a high power. This brings no vessels into view: on the contrary, it proves their non-existence beyond dispute. In some diseased states, however, the presence of a few vessels seems to have been established.

Mr. Toynbee* has pointed out, that the vessels of bone, at the part on which cartilage rests, are separated from the cartilage by a bony lamella, in which no apertures exist. The minute vessels, on approaching this lamella seem to dilate, and then, forming arches, they run back into the cancelli of the bone. Such an arrangement must, of course, be attended with a retardation of the blood near the "articular lamella." The vessels of the synovial membrane advance with it a little way upon the articular surface of the cartilage, but only over those parts which are not subject to pressure during the natural movements of the joint. These likewise terminate in loops. In diseased states they often advance far upon the cartilage as they do naturally, according to Mr. Toynbee's observations, during the middle period of fœtal life.

* Phil. Trans. 1841.

OF FIBRO-CARTILAGE.

This texture is a compound of white fibrous tissue and cartilage in varying proportions.

It is principally employed in the construction of joints, and contributes to their perfection at once by its strength and its elasticity; but as it is also, to a limited extent, used for other purposes, it may be conveniently described as, 1, Articular; 2, Non-articular.

Fibro-cartilage, examined by the naked eye, has much of the colour and general appearance of the thyroid cartilage, or of other examples of the membraniform variety, which Bichat, indeed, classed among fibro-cartilages. Its colour is white, with a slight tinge of yellow; it is interspersed by the shining fibres of white fibrous tissue, and its appearance differs with the quantity of that texture that is mingled with it. Its consistence also varies, for the same reason; in some instances being extremely dense, in others soft, yielding, and almost pulpy.

When examined microscopically, fibro-cartilage is found to consist of bundles of wavy fibres, with the cells or corpuscles of cartilage occupying the spaces formed by the interlacement of the fibrous tissue. This interlacement is often very intricate, and calculated to increase the strength of the structure in those directions in which the greatest toughness is required.

Physical and Vital Properties.— To the strength and density of fibrous tissue, fibro-cartilage adds the elasticity of cartilage; it is more variously flexible than the latter tissue, so that it will not crack when bent too much. Its sensibility is low, and it is devoid of vital contractility.

Vessels and Nerves.— Its vessels are few, and are derived from the textures (synovial membrane or periosteum) with which it is in immediate connexion. Nothing is known respecting its nerves, if indeed it possess them.

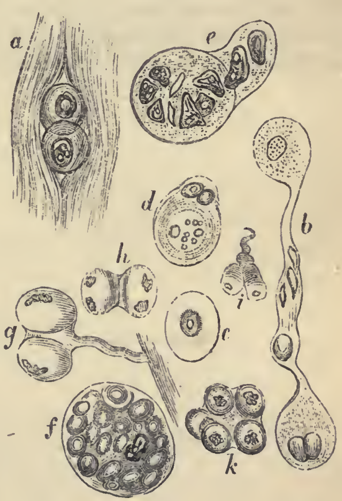
Chemical Composition.— Fibro-cartilage contains water; when deprived of it by drying, it shrivels up, and becomes hard and yellow. It yields gelatine in abundance on boiling.

Forms of Fibro-cartilage.— The *articular* fibro-cartilage is that which is found most extensively, and it exists in three forms. *a.* As *discs*, interposed between osseous surfaces, and equally adherent to both, of which the intervertebral discs and the interpubic fibro-cartilage are instances. *b.* As laminæ, free on both surfaces, placed in the cavity of diarthrodial joints between the articular surfaces of the bones. These are the *menisci* of authors; they exist in the temporo-maxillary, the sterno-clavicular, and the knee joints, and between the scaphoid and lunar, and lunar and cuneiform bones. *c.* As triangular edges to the glenoid and cotyloid cavities of the shoulder and hip joints. These are styled *circumferential.*

In examining these different forms of fibro-cartilage, some varieties are met with deserving of a brief notice.

The *intervertebral discs* consists of concentric layers of white fibrous tissue, placed vertically between the surfaces of the vertebræ: although the layers are vertical, the fibres of which each layer is composed, are directed obliquely from above downwards, and the direction of the fibres of one layer is such as to decussate with those of the layer immediately behind it. Each pair of layers of fibrous tissue is separated by a lamina of cartilage. This arrangement belongs to rather more than the outer third of the disc: the central portion is occupied by a soft, yielding, pulpy matter, which, when a disc is cut horizontally, rises up considerably above the surrounding level. This soft mass consists of a few bundles of white fibrous tissue (wavy fibres), with numerous nucleated cells, very variable in shape and size, loosely interspersed. It is girt by the surrounding vertical fibrous layers and their interposed cartilaginous lamellæ, and also compressed by the vertebræ between which it is placed; the pulpy matter being separated from immediate contact with the surfaces of the vertebræ by the interposition of thin layers of cartilage.

Fig. 17.



Elementary structures from an intervertebral disc:—*a.* Two cartilage-cells lying amongst the white fibrous tissue. The remaining objects are from the central pulpy substance, and exhibit various forms of cell. In several of these there is an appearance of multiplication by subdivision of the nucleus, and some seem attached by a fibrous tissue. The full meaning of this does not yet appear.

In the *menisci* the white fibrous tissue predominates considerably at their circumferences, while the cartilage chiefly abounds in the centre. Those of the knee joint and temporo-maxillary joint are the densest; that of the sterno-clavicular is softer and more cartilaginous.

The *circumferential* fibro-cartilages contain a considerable predominance of fibrous tissue.

The *non-articular* form of fibro-cartilage is found deposited on the surfaces of the grooves in bones, which lodge tendons; as, for example, the groove for the lodgement of the tibialis posticus. In intimate structure it resembles the articular forms.

Reparation and Reproduction.— Fibro-cartilage heals by a new substance of similar texture. Sometimes the union of bone is effected by a material of this kind, in cases where osseous union cannot be obtained.

In addition to the works on General Anatomy mentioned at the end of the last chapter, we refer to Müller's Physiology, by Baly, p. 390; the articles Cartilage and Fibro-cartilage, in the Cyclopædia of Anatomy; and Mr. Toynbee's paper on Non-vascular Tissues, in Phil. Trans. 1841.

CHAPTER V.

PASSIVE ORGANS OF LOCOMOTION, CONTINUED. — OF BONE.

The distinction of animal textures into hard and soft prevails very extensively throughout the animal series. The former are characterized by containing a proportion of inorganic material, in combination with animal matter, sufficient to give them that degree of hardness which is their principal physical property.

Among the invertebrated classes there are hard parts, although very differently constituted from those of the higher animals. They serve an analogous purpose, — being a basis of support for the soft parts, and in many instances a protection to them, and affording a surface of attachment for the muscles of the animal; thus playing an important part in its locomotion, or in its ordinary movements. To this category we may refer the earthy support to the soft fleshy mass, whether as an internal stem or axis, or as an external covering, which is to be found among the polypifera, performing a function similar to the skeleton of the higher animals, and composed of carbonate of lime, with a little phosphate, in combination with a small quantity of animal matter.

The calcareous plates of the star-fish and sea-urchin (*asterias* and *echinus*), the hard coriaceous covering of insects, the hard external integuments of crustacea, and the infinitely various shells of the gasteropoda and conchifera, must all be regarded in the light of hard parts performing the offices above referred to.

The skeleton of the higher animals is *internal;* it is clothed by the muscles and other soft parts. The first example of this arrangement is met with in the cephalopodous mollusks, in which certain cartilaginous plates are enclosed in the body of the animal, protecting certain parts of the nervous system. The skeleton of the lowest organized fishes, although much more extensive, and of a more complicated arrangement, is yet placed but little above that of those animals. It is composed of a kind of cartilage, which in its greater density, and in its having a certain quantity of calcareous deposit around it, approaches the nature of the skeleton of the higher classes.

Bone is the substance employed to form the internal skeleton of the osseous fishes, of reptiles, birds, and mammalia. It forms organs of support, or levers for motion, or it encloses cavities, affording protection to soft and vital organs.

To a superficial examination bone presents the following properties: hardness, density, a whitish colour, opacity. An examination of its physical constitution will explain these characters.

Bone contains less water than any other organ in the body; and exposure to air, even for a short time, removes the fluid by evaporation: to this, in part, may be attributed its hardness. Bone consists of an inorganic and an organic material, which may be obtained separately by very simple processes. Steep a bone in dilute mineral acid, muriatic or nitric; the earthy matter is dissolved out by the acid, and the organic substance remains, retaining the original shape and size of the bone. In fact, we obtain, by this process, the cartilaginous nidus of the bone, upon which its form depends. The vessels of the bone ramify throughout this mass; for if they have been injected previously to the action of the acid, they will be distinctly seen ramifying through the semi-transparent animal substance. A preparation of this kind dried, and afterwards preserved in spirits of turpentine, serves beautifully to exhibit the disposition of the vessels in bone.

By subjecting a bone to a strong heat in a crucible, the animal part will be burnt out, and the earthy part will remain. Still the bone retains its form, but the cohesion between the earthy particles is extremely slight, so that the least touch will destroy its continuity; a fact which obviously points to the animal matter as affording to bone its strength of cohesion.

Bone may be deprived of its animal matter by long-continued boiling, under strong pressure, in a Papin's digester. The animal matter is extracted, in combination with water, in the form of *gelatine;* and the weight of the quantity which may thus be obtained will, owing to this union with water, exceed by three or four times that of the bone itself.

A certain proportion between these two constituents of bone is necessary to the due maintenance of its physical properties. To the earthy part it owes its hardness, its density, its little flexibility: but it is equally necessary for these properties that the animal portion shall be healthy, and in proper quantity; for the cohesion of the particles of the former is secured entirely by it. A due proportion of the animal part gives bone a certain degree of elasticity; and, were it not for the earthy matter, bones would be exceedingly flexible, as may be shewn in a bone deprived of its calcareous matter by acid. Hence old bones, in which the animal matter is less abundant, as well as perhaps defective in quality, are more brittle than young ones, and old persons are more liable to fractures. But in the young, in whom the organic processes are active, and whose animal matter is fully adequate in quantity and quality to the wants of the system, the bones possess their due degree of flexibility, and hence in them fractures are less frequent; the cohesive force of the bones being sometimes so considerable, that they will bend to a great degree before yielding.

The following table from Schreger illustrates the relative proportions of the two constituents, at three periods of life, in 100 parts of bone:

	Child.	Adult.	Old.
Animal matter . .	47·20 .	20·18 .	12·2
Earthy matter . .	48·48 .	74·84 .	84·1

or it may be stated in general terms, that in the child the earthy matter forms nearly one half the weight of the bone, in the adult it is equal to four fifths, and in the old subject to seven eighths; a conclusion agreeing in the main with that drawn from the analyses of Davy, Bostock, Hatchett, and others.

It had long been known that certain bones of the body contained these constituents in other proportions than those named; for example, the petrous portion of the temporal bone had been shewn by Davy to owe its stony hardness to a large proportion of earthy matter. But Dr. G. O. Rees has lately pointed out some interesting particulars as to the relative proportions of these elements in the composition of different bones.

The long bones of the extremities have, according to Dr. Rees' analysis, more earthy matter than the bones of the trunk. The bones of the upper extremity have a larger proportion of the same material than those of the corresponding bones in the lower; the humerus has more than the radius and ulna; the femur more than the tibia and fibula; while the bones of the fore-arm, as well as those of the leg, are respectively alike in constitution. The vertebræ, ribs, and clavicles are similarly constituted. The ilium has more earthy matter than the scapula or sternum; the bones of the head have more of this material than those of the trunk.

In the fœtus the same law prevails as regards the relative quantity of the earthy matter, excepting that the long bones, and the cranial bones, do not contain the excess of earthy matter which characterizes them in the adult.

The diseased state, called Rickets, so common in the children of scrofulous parents, and in the ill-nourished ones of the lower orders, consists in a deficient deposit of earthy matter; the animal matter being probably of an unhealthy quality. In this disease the bones are so flexible, that they bend under the weight that they may be called on to support, or under the action of the muscles. The lower extremities exhibit deformity first, and to the greatest degree, and the direction in which they become bent is evidently influenced by the superimposed weight; the bend almost always appears as an aggravation of the natural curves of the bones. The rickety femur has always its convexity directed forwards: the tibia is convex forwards and outwards, and the fibula follows the same direction. When the nutritive powers of the system are fully restored, the deposition of earth goes on in its healthy proportion, the animal matter becomes healthy, and the bones acquire their due degree of strength and hardness. In the tibia of a rickety child, Dr. Davy found, in 100 parts, 74 parts animal matter, and 26 earthy; and Dr. Bostock found in the vertebra of a similar subject 79·75 animal, and 20·25 earthy.

The brittleness of the bones in old age is due to an opposite cause, namely, the defective deposit of animal matter, so as to give to the earthy matter the undue preponderance already specified. But this state cannot be looked upon as morbid; it is the natural result of the feeble condition of the powers of nutrition, which ensues in the advance of years; and it will vary, in different individuals, according to the original strength of constitution of each, and according to the freedom from exposure to debilitating influences.

That state of bone which accompanies malignant disease (cancer, or fungoid disease) in adults or old persons, and which some pathologists have designated *mollities ossium,* results from the dissemination of cancerous matter through the system. In this disease, the whole nutritive process of bones seems tainted; the animal part is not so much deficient in quantity as bad in quality; the physical as well as the vital properties of the bone are completely deranged; the osseous texture has lost its cohesive power. Hence these bones often break on the application of the slightest force, or on the feeblest exercise of the muscles. They are soft, too, in the recent state; the knife will sometimes penetrate them; and they are often pervaded by a considerable quantity of oil.

Bones possess a remarkable power of resisting decomposition. Even the animal part seems to acquire this power through its combination with the earthy. This is manifest from analysing bones which have been long kept, or fossil bones. Cuvier states that the latter bones exhibit a considerable cartilaginous portion; and

Bichat found that clavicles, which had been exposed for ten years to the wind and rain at the cemetery of Clamart, presented, under the action of acid, an abundant cartilaginous parenchyma. In an old Roman frontal bone, dug up from Pompeii, Dr. Davy found 35·5 animal parts, and 64·5 earthy; and in a tooth of the mammoth, 30·5 animal, and 69·5 earthy.

The animal part of bone consists of cartilage, with vessels, medullary membrane, and fat. The cartilage is readily convertible into gelatine, according to Berzelius, after three hours' boiling; and, when this has been removed, there remain only four grains out of 100, which may be considered to have been composed of blood-vessels.

The earthy part of bone consists of phosphate and carbonate of lime, with a small quantity of phosphate and carbonate of magnesia. The phosphate of lime forms the principal portion of the earthy part: in 100 parts of bone Berzelius found 51·04 of this salt. It was discovered by Gahn, and the discovery announced by Scheele, that bone-earth consisted of "phosphoric acid and lime." According to Berzelius, the phosphate consists of eight atoms of lime and three atoms of phosphoric acid; but Mitscherlich regards it as composed of three atoms of lime with one of phosphoric acid (a tribasic salt). It may be formed artificially by dropping chloride of calcium into a solution of phosphate of soda. It appears as a gelatinous precipitate, which does not crystallize, and is readily soluble in acids.

The existence of fluoride of calcium in bone was announced many years ago by Berzelius; but the observations of our friend, Dr. G. O. Rees, throw considerable doubt upon this assertion. Dr. Rees attributes the action of the supposed fluoric acid upon glass to phosphoric acid in combination with water, which, if heated on glass of inferior quality until it volatilizes, will act upon it with considerable energy. The proportion of carbonate of lime to the phosphate is small. According to Berzelius, there are 11·30 parts in 100 of bone.

We subjoin the following process, by which the qualitative analysis of bone may be readily effected:

In order to insulate the *animal matter*, digest the bone for some days in muriatic acid diluted with about thrice its bulk of water; the earthy constituents will thus be gradually removed, leaving a semi-transparent cartilaginous tissue behind.

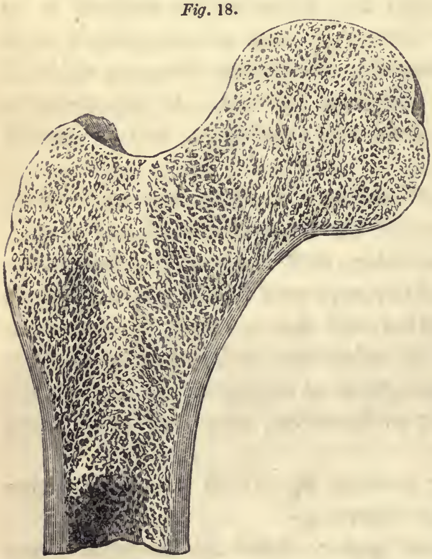
The *earthy matters* are best examined by treating a portion of burnt bone with nitric acid, diluted with from four to six times its bulk of water; brisk effervescence ensues, proving the presence of *carbonic acid.* Filter the acid liquid after diluting it with water, and add solution of caustic ammonia as long as the precipitate at first formed continues to be redissolved by agitation; then add solution of acetate of lead till it no longer occasions any precipitate. The dense white precipitate thus produced consists of *phosphate of lead*, which melts before the blow-pipe, and on cooling assumes its characteristic crystalline structure.

Through the solution, filtered from the phosphate of lead, pass a stream of sulphuretted hydrogen to remove the excess of lead; warm the liquid, to drive off the superfluous gas, and filter: then neutralize by ammonia, and add oxalate of ammonia as long as any precipitate occurs; abundance of *oxalate of lime* will fall as a white powder.

Evaporate the filtered liquid to dryness; ignite the residue, and wash with hot water; the *magnesia* will be left behind in a pure form.

In examining a section of almost any bone, we observe two varieties of osseous substance: the one dense, firm, compact, always situated on the exterior of the bone, either as a thin layer, or as a dense thick structure possessed of great strength; the other loose, reticular, spongy, enclosing spaces or cells, which communicate freely with each other, and which, being called *cancelli*, give to this kind of osseous tissue the name *cancellated.* These cells are formed by an interlacement of numerous bony fibres and laminæ, which, although to a superficial observation exhibiting an indefinite arrangement, have nevertheless, in those bones which have to support weight, a more or less perpendicular direction. The cancellated structure of bone is always situated in its interior, enclosed and protected by the compact tissue.

Fig. 18.



Vertical section of the upper end of the Femur, shewing the cancellated and compact tissues.

The relative situation of these varieties may be well seen in a vertical section of one of the long bones (fig. 18). At the *extremities*, the cancellated texture is accumulated, invested by a thin lamella of compact tissue, giving expansion and lightness to those parts of the bone. In the intermediate portion, or *shaft,* the compact tissue is highly developed, affording great strength in the situation where that quality is the most needed.

The compact external surface of bone (except on its articular aspects) is covered by a firm tough membrane, termed the *periosteum,* which, like the perichondrium investing cartilage, consists of white fibrous tissue, densely interwoven in all directions. The cancelli are filled with fat, or *medulla,* the marrow of bone. They are lined by a delicate membrane, called the *medullary membrane,* which serves to support the fat. In the shaft of the long bones the medulla is contained, not in ordinary cells, but in one great canal, which occupies the centre of the shaft, the *medullary canal.* Here the medullary membrane lines the compact tissue that forms the wall of the cavity.

Both the periosteum and the medullary membrane adhere intimately to the bone. Both are abundantly supplied with blood-vessels, which, after ramifying upon them, send numerous branches into the bone. These membranes are of great importance to the nutrition of the bone, inasmuch as they support its nutrient vessels; and, if either of them be destroyed to any great extent, the part in contact with them necessarily perishes: and they not only cover the outer and inner surfaces of the bone, but also send processes, along with the vessels, into minute canals traversing the compact tissue, and are, through the medium of these, rendered continuous with one another.

The great variety of uses to which the bones are applied in the construction of the skeleton, occasions much difference of shape as well as of size. The following arrangement comprehends all these varieties, and is that commonly adopted. We classify them as, 1, Long bones; 2, Short; 3, Flat; 4, Irregular.

The *long* bones form the principal levers of the body; their length greatly exceeds their breadth and thickness. In descriptive anatomy, a long bone is divided into a shaft, or central part, and two extremities. The shaft is never perfectly straight, it is more or less curved, as in the femur; and has always an appearance as if, while yet in a soft and flexible condition, it had received a twist, and its extremities had been turned in opposite directions. This is very manifest in the femur and humerus; more especially in the latter, where the groove, in which the radial nerve runs, is just what one might fancifully suppose to have resulted from such a cause as that above named.

The shaft is never perfectly cylindrical: although in some bones it approaches that form, in others it is prismatic. It is hollow, as already mentioned, and contains medulla. This arrangement has the advantage of making the bone very much lighter than it would have been if solid; while it is attended with no sacrifice of strength, since the central osseous substance is that which contributes least to its power of resistance.

The strength of the shaft is amply provided for by its being composed of compact tissue, of thickness proportionate to the length of the bone, and the bore of the medullary canal. In the curved bones, additional strength is obtained in the position where the bone would be most likely to yield, by increased thickness and density along its concavity. Of this provision a good example will be found in the spine of the femur,—a ridge of extremely dense bone, placed along its posterior concave surface. In the bent bones of rickety subjects which have become fully ossified, the compact tissue on the concavity of the bend acquires an enormous development.

At the extremities of the long bones the medullary canal ceases; the osseous tissue expands; and the cancellated texture takes the place of the compact substance of the shaft, and forms the whole thickness of these portions of the bone, the medulla penetrating into its cells. Here great strength is not required, but surface is needed for the articulation of the bones together, and for affording attachment to ligaments and tendons. The cancellated tissue is admirably adapted to attain this object; for, while by the looseness of its texture it readily affords an extent of surface, its lightness is such, that even a considerable bulk of it does not materially affect the weight of the bone. The surface of this texture is covered with a thin cortex of compact tissue, which is perforated by innumerable orifices for the transmission of vessels.

The long bones are the great levers of the extremities; as the bones of the thigh and leg, arm and fore-arm. Among the bones of the hand and foot are certain ones which have all the anatomical characters of the long bones, except that of length; they may, therefore, be grouped together in a class under the name of *short* bones. These are, the metacarpal and metatarsal bones, and the phalanges of the fingers and toes.

The *flat* bones are remarkable for their slight thickness; they are composed of two thin layers of compact tissue, enclosing a layer of cancellated texture of variable thickness. Examples of this class of bones may be found in most of those enclosing the great cavities of the body; as the bones of the cranium, the ribs, the scapula, the os innominatum, all of which will be found to possess the same essential characters.

The cranial bones present one or two peculiarities which demand a special notice. The layers of compact tissue in them are familiarly known as the *tables* of the skull: the outer one is stouter and tougher; the inner one denser and much thinner, and therefore more brittle. The intervening structure is called the diploë; in some places it is absent, leaving a vacant space produced by the separation of the tables, and which communicates with the external air, as in the frontal sinuses; the diploë is generally a very fine cancellated texture; but, in the mastoid process of the temporal bone, it is of a much looser kind, its cancelli are larger, and instead of being occupied by medulla, as elsewhere, they communicate with the cavity of the tympanum, and are therefore always filled with air. The diploë of the cranial bones in birds is everywhere devoid of medulla, and occupied by air, which gains access to it from the tympanum.

A fourth group of bones consists of those, which seem to combine many of the offices and forms of the three preceding ones with certain characters proper to themselves. They exhibit much irregularity of shape and size; and, on this account, are called *irregular* bones. The vertebræ, the tarsal and carpal bones, certain bones of the head and face, belong to this group. Lightness, with extent of surface, are their principal characters. They are composed mainly of cancellated texture, covered by a layer of compact, and here and there a portion of compact tissue, for the purpose of affording a firm bond of connexion of some process to the main part of the bone; as the pedicles, uniting the laminæ to the bodies of the vertebræ.

In examining the surfaces of these different groups of bones, we are struck with the variety of projections or eminences, and of depressions, which are found upon them. These are of two kinds: articular, and non-articular. The former are destined for the formation of joints: as the head of the thigh-bone, an articular eminence; and the acetabulum, an articular depression.

The non-articular eminences chiefly serve as points of insertion for ligaments and tendons, and exhibit a great diversity of shapes, so that anatomists designate them as tuberosities, tubercles, spines, cristæ, &c. The non-articular depressions serve a similar purpose, and are equally various in form, being described as fossæ, cells, furrows, grooves, fissures, pulleys, &c.

With reference to these eminences and depressions, it may be observed that they are well marked in proportion to the muscularity of the subject. In the female, for instance, they are less distinct than in the male; in the powerfully muscular man they are at the maximum of development. As Sir Charles Bell has remarked, a person of feeble texture and indolent habits has the bone smooth, thin, and light; while with the powerful muscular frame is combined a dense and perfect texture of bone, where every spine and tubercle are well developed. And thus the inert and mechanical provisions of the bone always bear relation to the muscular power of the limb; and exercise is as necessary to the perfect constitution of a bone, as it is to the perfection of muscle. It is an interesting fact, that if a limb be disused, from paralysis, the bones waste as well as the muscles.

Of the Vessels of Bone.—We now proceed to inquire into the manner in which the nutrition of bone is provided for. A texture containing so much animal matter, and needing a constant supply of inorganic material likewise, must necessarily be largely supplied with blood, the common source of the materials of all the tissues.

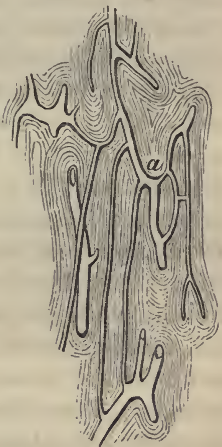
The blood-vessels of bone are very numerous, as may be satisfactorily seen on examining a well-injected specimen. The arteries are in great part continued from those of the periosteum: those which penetrate the cancellated texture of the extremities of the long bones are very large, and ramify freely among the cancelli.

The membrane of the medulla which is contained in the shaft, receives its blood from a special artery that pierces the compact tissue through a distinct canal, known as that for the nutritious artery. This vessel divides into two immediately on entering the medullary canal; of these, one ascends, the other descends, and both break up into a capillary network, anastomosing with the plexuses in the extremities of the bone, derived from the arteries that penetrate there. From the copious vascular network thus formed within the bone, the innermost part of the compact substance of the shaft receives its blood-vessels.

In the compact tissue the arteries pass into very narrow capillary canals, most of which are invisible to the naked eye. In carefully raising the periosteum from a bone that has been subjected to a little maceration, the vessels may be seen in great numbers passing from that membrane into the osseous texture, and many of the larger ones seem to be surrounded by a sheath derived from the periosteum. Similar sheaths may be seen surrounding the vessels of the cancellated texture.

The vascular canals of the compact tissue are styled *Haversian,* after their discoverer, Clopton Havers. They are disseminated pretty uniformly through the tissue, and inosculate everywhere with one another. In the long and short bones they follow the same general direction as the axis of the bone, and are joined at intervals by cross branches. The meshes thus formed are more or less oblong (fig. 19). The deeper ones open into the contiguous cancelli, with the cavities of which they are continuous.

Fig. 19.



Haversian canals, seen on a longitudinal section of the compact tissue of the shaft of one of the long bones:—*a.* Arterial canal. *b.* Venous canal. *c.* Dilatation of another venous canal.

The arteries and veins of bone usually occupy distinct Haversian canals. Of these the venous are the larger, and commonly present at irregular intervals, and especially where two or more branches meet, pouch-like dilatations, calculated to serve as reservoirs for the blood, and to delay its escape from the tissue. In many of the large bones, particularly in the flat and irregular ones, the veins are exceedingly capacious, and occupy a series of tortuous canals of remarkable size and very characteristic appearance. These are well described by Breschet in his elaborate work on the venous system; from which the accompanying figure (fig. 20) is taken. These canals run, for the most part, in the cancellated structure of the bones, and are lined by a more or less complete layer of compact tissue, which itself often contains minute Haversian canals. The veins they contain discharge themselves separately on the surface.

Fig. 20.

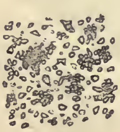
Venous canals in the diploë of the cranium.—After Breschet.

The Haversian canals vary in diameter from $\frac{1}{2500}$ to the $\frac{1}{200}$ of an inch, or more, the average being about $\frac{1}{500}$. Their ordinary distance from one another is about $\frac{1}{120}$ of an inch. They may be regarded as involutions of the surface of the bone, for the purpose of allowing vessels to come into contact with it in greater abundance. It is evident that the cancelli, and even the great medullary canal itself, are likewise involutions of the osseous surface, though for a partly different end. These larger and more irregular cavities in bone may be considered as a dilated form of Haversian canals. They contain vessels not only for the nutrition of the thin osseous material forming their walls, but also for the supply of the fat enclosed within them.

Thus the true osseous substance may be described as lying in the interstices of a vascular membrane, or of a network of blood-vessels. The most interesting points in the minute anatomy of bone relate to the mode in which nutrition is provided for in those parts not in immediate contact with the blood-vessels. We have already seen that considerable masses of cartilage derive their nutriment from vessels placed on their exterior only, apparently by a kind of imbibition, perhaps aided by the presence of the nucleated cells, and by a more or less fibrous texture: but bone, which is of a far harder and denser nature, is unable to imbibe its nourishment so easily. Hence its surface is greatly augmented by the arrangements already detailed; and, in addition to this, the osseous tissue itself is provided with a special system of microscopic cavities and canaliculi, or pores, by which its recesses may be irrigated, to a degree of minuteness greatly exceeding what could have been effected by blood-vessels alone, consistently with the compactness and density required in the tissue. The study of this delicate apparatus will now demand attention; but a few words must be premised on the ultimate structure of the *osseous tissue.*

It appears from the researches of Mr. Tomes, about to be published in the Cyclopædia of Anatomy, that the ultimate structure of the osseous tissue is *granular.* The granules of bone are often very distinctly visible, without any artificial preparation, in the substance of the delicate spiculæ of the cancelli, viewed with a high power, and in various sections of all forms of bone. They may be generally obtained in calcined bone, either by bruising a fragment of it, or by steeping it in dilute muriatic acid; they may also be made very evident by prolonged boiling in a Papin's digester. Those represented in fig. 21 were obtained in the latter mode. The granules vary in size from $\frac{1}{6000}$ to $\frac{1}{14000}$ of an inch. In shape they are oval or oblong, and often angular. They cohere firmly together, possibly by the medium of some second substance. In some few instances, Mr. Tomes has met with a very minute network, which seems adapted to receive them in

Fig. 21.

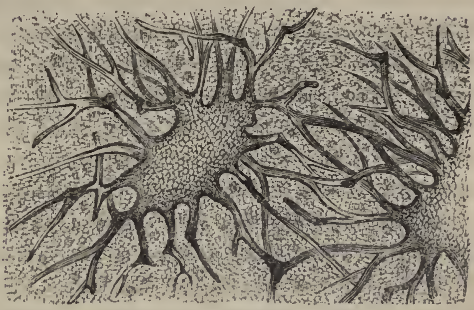


Ultimate granules of bone, isolated and in small masses, from the Femur.—(From a preparation of Mr. Tomes.) Magnified 320 diameters.

its interstices; but this he considers to require confirmation. A frequent apperance of the granular texture is well represented in fig. 22.

Where bone exists naturally in an exceedingly attenuated form, it may consist of a mere aggregation of these granules, unpenetrated by any perceptible pores. This constitutes the simplest form under which the tissue can present itself.

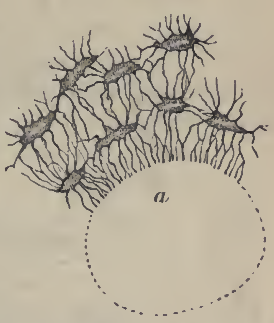
Fig. 22.



Two lacunæ of osseous tissue, seen on their surfaces, shewing the disposition of their pores. The granular aspect of the tissue both on their walls and around them is well represented.—Magnified 1200 diameters. Drawn from a preparation of the cancelli of the Femur made by Mr. Tomes.

But all the osseous tissue with which the human anatomist is concerned is of such bulk as to contain the series of pores and cavities already alluded to for the conveyance of fluid from and to its vascular surface. These *pores* always advance into the bone from open orifices on its surface. They soon arrange themselves in sets, each of which, after anastomosing with neighbouring ones, discharges itself into a small cavity or *lacuna*, in which its individual pores coalesce. From the sides of this lacuna other pores pass off to similar cavities in the vicinity, and others proceed from its opposite surface to penetrate still deeper into the tissue. These pour themselves into another lacuna, or divide themselves between two or three, which are connected in like manner by lateral channels. From these again pass others, which pursue an onward course from the surface; and so on, until the whole substance of the bone is perforated by them. The pores from the further side of the extreme lacunæ either open on the surface of the bone which they may now have reached, or else take a recurved direction back into the tissue.

Fig. 23.

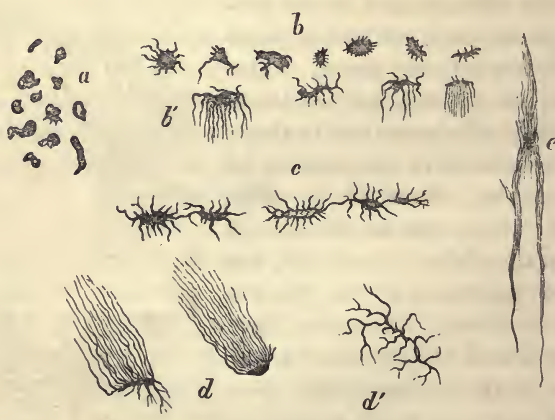


Transverse section of a part of the bone surrounding an Haversian canal, shewing the pores commencing at the surface, *a*, anastomosing and passing from cavity to cavity.—Magnified about 300 diameters. From a preparation made by Mr. Tomes.

When this beautiful system of microscopic pores and cavities was first seen, it was not recognised as such. The lacunæ were imagined to be solid *corpuscles* (a name still commonly applied to them), and the lines radiating from them to be branching threads of the earthy constituent of bone. They may be proved in many ways, however, to be real excavations in the tissue. With a sufficiently high power their opposite walls can be distinctly seen, as well as their hollow interior; but the most conclusive evidence lies in our being able to fill them with fluid. If a dry section of bone, in which they are very apparent, be moistened with oil of turpentine while in the field of the microscope, the course of this penetrating material can be witnessed, as it advances into the tissue. It is seen to run quickly along the pores from the Haversian canals, and from the surface of the specimen, where they have been cut across. Having entered a lacuna, it suddenly extends along the pores radiating from it, and, through these, reaches other lacunæ; rendering the tissue transparent by filling up its vacuities. In parts where air has previously occupied the vacant spaces, and the turpentine cannot displace it, the characteristic appearance of minute bubbles is often present.

The *lacunæ* of osseous tissue, if examined extensively in the vertebrate class, are found of very various shapes: sometimes scarcely to be distinguished from the pores, of which they are simple fusiform dilatations; at other times large and bulky, and forming the point of junction of a great multitude of pores. Mr. Tomes has allowed us to represent the principal varieties which he has met

Fig. 24.



Form of various Lacunæ, and their pores:—*a*. Simple irregular cavities, without pores; from an ossification of the pleura: *b*. from healthy bone of the human subject. *b′*. One of the outer lacunæ of an Haversian system, with the pores all bending down towards the H. canal. *c*. Other forms from human bone, shewing the lateral connecting pores.

d. From the Boa. External lacunæ of an H. system, with unusually large pores dipping towards the vascular surface. *d′*. Cavity intermediate between a lacuna and a pore. *e*. Another variety from the same reptile.—From Mr. Tomes.

with in the human subject; and some remarkable ones from the lower animals are appended from the same source (fig. 24). In the true *dental* substance, which is a kind of bone, the lacunæ are almost entirely deficient, and the pores attain a very singular development, which will be described in a subsequent chapter.

But though varieties are occasionally met with, yet, in the true bone of man and the mammalia, the lacunæ possess a very constant form; being somewhat oval, and more or less flattened on their opposite surfaces. The two surfaces look respectively to and from the nearest surface of the tissue, and meet in a thin edge. As pores pass off equally from all parts of the lacunæ, it follows that by far the greater number pass to or from the surface of the bone; an arrangement admirably adapted for the transmission of the nutritious fluids. The pores passing from the edge principally serve to connect together those lacunæ that lie at nearly the same distance from the surface. In fig. 22, the lacunæ are seen on their surface; in fig. 23, on their upper edge.

The lacunæ have an average length of $\frac{1}{1800}$ of an inch, and they are usually about half as wide, and one third as thick. The diameter of the pores is from $\frac{1}{20000}$ to $\frac{1}{12000}$ of an inch.

The osseous tissue, thus studded by thousands of flattened lacunæ, which lie for the most part in planes parallel to the surface, has a decided disposition to split up into *laminæ*, following the same direction. This is more evident in the bones of old persons, and may be generally promoted by maceration in dilute acid. It is most apparent where the mass of material between two vascular surfaces is great, and the series of lacunæ numerous. It is probable that this lamellated structure depends in part on the mode of development and growth of this tissue, and it perhaps contributes to the perfection of the nutritive process within it.

It will now be easy to comprehend the apparently complex arrangement of the osseous tissue in the interior of bones. Let us take, for example, one of the long bones. The entire vascular surface consists of, 1, the *outer surface*, covered by the periosteum; 2, the *inner surface*, lined by the membrane of the medullary cavity, and of the cancelli; 3, the *Haversian surface*, or that forming the canals of the compact tissue, and having in contact with it the vascular network that occupies them, and which has been already described. These involutions of the surface are so arranged that no part of the osseous tissue is in general at a greater distance than $\frac{1}{170}$ of an inch from the vessels that ramify upon them.

There is a layer of tissue on the exterior of the bone deriving its nourishment from the periosteum, and which may be called the *periosteal layer.* The lacunæ of this layer, all face that surface, and the pores of the superficial ones open upon it. There is another layer, forming the immediate wall of the medullary cavity, and termed the *medullary layer.* Its lacunæ, in like manner, face this cavity; and the pores of the inner ones open upon it. This layer becomes variously folded to form the plates and fibres of the cancelli; and all the lacunæ of these face these irregular cavities, and their pores open into them. The Haversian surface, too, being an involution of the outer and inner surfaces, and serving to connect them, is, in fact, formed by an involution of the periosteal and medullary layers, and unites these with one another. Where a vessel enters the compact tissue from the exterior, it carries with it a sheath of bone from the periosteal layer. The lacunæ of this osseous sheath, instead of being turned outwards, like those of the periosteal layer, preserve their relation to the vascular surface to which they pertain, and face *inwards* towards the vessel. Wherever the vessel penetrates, whatever direction it takes, and however it branches, it is everywhere accompanied by this sheath from the periosteal layer, or by offsets from it; and, when it enters the medullary canal, its sheath expands into the medullary layer.

The vessels of the compact tissue are so close together that the osseous sheaths respectively surrounding them come into contact and unite; and thus all the space between the outer and the inner surface of the compact tissue is filled up: thus, in a word, the compact tissue is constructed.

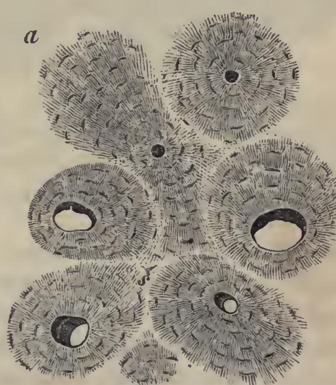
Fig. 25.

Transverse section of the compact tissue of a long bone; shewing, *a*. The periosteal layer. *b*. The medullary layer, and the intermediate Haversian systems of lamellæ, each perforated by an H. canal.—Magnified about 15 diameters.

As the vessels of the compact tissue take a longitudinal direction, a transverse section of the bone (fig. 25) will appear pierced by numerous holes, which are the Haversian canals cut across. Each hole appears as the centre of a roundish area, which is the section of an involuted periosteal layer now become a vertical rod, containing a vessel in its axis. The Haversian canals vary considerably in size, and do not maintain a very close relation to the thickness of their respective osseous walls. They are frequently eccentric, owing to their wall bulging more in one direction than another, to fit in between others in the vicinity: for though the rods of bone, containing the vessels, affect the cylindrical form, they often present an oval, or even a very irregular, figure, on a section; their close package having modified their form. The periosteal and medullary layers are also well seen on the same section, the latter curving inwards to constitute the walls of the cancelli. These two layers are of very irregular thickness, as the Haversian rods encroach on them unequally (fig. 25).

On a further examination of such a section, with a sufficient magnifying power, we observe the lacunæ of the periosteal and medullary layers facing those surfaces, and their pores opening upon them; while the lacunæ of each Haversian layer all face the corresponding canal, and their pores radiate from it (fig. 26, and the previous fig. 23, more highly magnified). The lacunæ facing the Haversian surface are generally curved concentrically with it. They are more numerous, and their pores more abundant, on the side where there is most osseous substance, and where it consequently extends furthest from the source of nutriment, the Haversian vessel. The reason of the want of proportion between the width of the canals and the thickness of their respective osseous walls, appears to be this, that the larger canals transmit vessels to other parts, besides containing those which nourish their own layer; while some of them are, no doubt, in a great measure channels for veins.

Fig. 26.



Part of the preparation represented in the last figure, more highly magnified: shewing the package of the Haversian systems, and also the light spaces between neighbouring ones. The system, *a*, appears to fill up an interval between the others. The lacunæ are seen facing the Haversian canals, and their pores taking a general radiating direction. At *s*, an irregular lacuna communicates with the pores of three contiguous systems.

The outer lacunæ belonging to an Haversian canal sometimes send out pores to anastomose with those of the neighbouring rods; but this seems to happen chiefly where the contiguous rods have just sprung from a common stock. Occasionally, also, lacunæ of irregular shape (as at *s*, fig. 26) lie in the interval of two or more rods, and communicate with lacunæ of all of them; but, in general, the outermost pores of the extreme lacunæ droop back on all sides (fig. 24, *b′*, *d*), and re-enter the penultimate series of their own rod.

Owing to this arrangement, there always appears a transparent interval between contiguous rods; the pores and lacunæ not existing there to intercept the passage of the light (fig. 26). This is a remarkable circumstance, and will be illustrated when we come to speak of the development of bone.

The *lamellated* character of bone can be frequently distinguished in the periosteal, medullary, and Haversian layers; and, in general, wherever several successive series of lacunæ exist. The Haversian rods, however, are remarkably prone to exhibit this appearance, especially under the conditions previously mentioned (p. 111). Their lamellæ, however, are not concentric, as commonly described. The fissures which disclose them are indeed concentric, but they are always incomplete, never extending completely round the canal; so that the lamellæ run into one another at various points. This results from the fact, that the lacunæ are not arranged in sets equidistant from the centre, but are scattered, as it were, independently of one another, at every possible variety of distance from the canal (figs. 23 and 27). The larger concentric cracks, which generally run through the lacunæ, seem to occur where two or three of these happen to lie nearly in the same curve. Bone is very apt to crack in the interval between the rods; and each of these rods is really so distinct from those near it, that it may be designated conveniently, for the purposes of description, as an *Haversian system of lamellæ.*

Fig. 27.

Transverse section of the compact tissue of a tibia from an aged subject, treated with acid; shewing the appearance of lamellæ surrounding the Haversian canals. Portions of several systems of lamellæ are seen. The appearance of the lacunæ, when their pores are filled with fluid, is also seen, as well as the radiation from the canals which then remains. —From Mr. Tomes.

In a longitudinal section of the compact tissue of a long bone (fig. 19, p. 107) the appearance of lamellation is generally less evident, except where a longitudinal canal happens to lie exactly in the plane of section. When the Haversian canal is a little below the cut surface, it is of course covered by some of its lamellæ, the lacunæ of which directly over it are seen in face, while the lamellæ dipping in on either side, in their course round the canal, present the thin edges of their lacunæ to the observer. In the former part those pores alone are seen that proceed from the edge of the lacunæ; while in the latter those from both surfaces are seen, and of course appear much more numerous.

The description now given of the intimate texture of the compact tissue of long and short bones will apply, in all essential respects, to every other example of the compact tissue; the chief difference consisting in the direction taken by the Haversian canals, which is irregular where the tissue follows an irregular course. In general, however, the canals, with the Haversian rods forming their sheaths, run in the direction in which the tissue needs the greatest strength. Thus, in the long bones it is vertical; and in those flat bones, which have to support weight, it is also more or less vertical; while in those designed to sustain the action of forces of other kinds it is liable to corresponding variety.

So beautifully mechanical is this disposition of the Haversian systems in the compact tissue, that we need not smile at the descriptions of Gagliardi, who, with imperfect means of observation, appears to have been at least faithful in his attempts to delineate nature. The periosteal and medullary layers are true *plates* of bone, and the Haversian systems are true fibres or *pins*, all connected with one another by direct continuity of tissue, and most artfully arranged for the mechanical ends in view: and we cannot sufficiently admire the skill which has caused the means, employed for these ends, to conspire with those which were indispensable for the due nutrition of the tissue.

In the ordinary cancellated texture, each cancellus must be regarded as a little medullary cavity, containing, as it does, medulla and highly vascular medullary membrane. The plates of bone which form its walls consist of lamellæ, among which lacunæ, with their pores, are scattered; and they sometimes, when thick, contain Haversian canals. Usually, however, the pores of these laminæ communicate directly with the cavity of the cancellus to which they belong.

Nerves of Bone.—The skill of anatomists has hitherto failed to demonstrate the presence of nerves in the interior of bones. Some nerves pass through bones, but no supply strictly to the osseous matter has yet been proved. Yet there is little doubt that the vascular surface of bones is furnished with nerves; the painfulness of many affections of the periosteum, and of the medullary membrane, seems to place this beyond dispute.

Development.—In the earliest period at which the skeleton can be detected among the other tissues of the embryo, it is found to consist only of a congeries of cells, constituting the simplest form of cartilage. These increase in number and in density, and become surrounded and held together by an intercellular substance in small quantity; thus forming the *temporary cartilage,* which subsequently becomes converted into bone. The temporary cartilages have the same general shape before as after their ossification; and as this process is slow, and not finally completed until adult age, they share during a considerable period in the functions of the bony skeleton.

Until the completion of the process of ossification, the temporary cartilages increase in bulk by an interstitial development of new cells. A few vessels, also, shoot into them at an early period, occupying small tortuous canals, which subsequently become obliterated.

Ossification commences in the interior of the cartilage at determinate points, hence called *points* or *centres of ossification.* From these the process advances into the surrounding substance. The period at which these points appear varies much in the different bones, and in different parts of them. The first is the clavicle, in which the primitive point appears during the fourth week: next is the lower jaw; the ribs, too, appear very early, and are completed early; next the femur, humeris, tibia, and upper jaw. The vertebræ and pelvic bones are late, as well as those of the tarsus and metatarsus. Some bones do not begin to ossify till after birth, as the patella.

Fig. 28.

Vertical section of the knee-joint of an infant; shewing the points of ossification in the shaft and epiphysis of the femur and tibia, and in the patella. A few vascular canals are also seen in the cartilage. Natural size.—From the Museum of King's College.

In most bones ossification begins at more than one point. Thus, in the long bones (fig. 28) there is a middle point, to form the future shaft; and one at each extremity, to form the articular surface and eminences. That in the shaft is the first to appear, and the others succeed it at a variable interval. The central part is termed the *diaphysis,* and for a long period after birth there remains a layer of unossified cartilage between this and the *epiphyses,* as the extremities are then styled. *Processes* of bone have usually their own centres of ossification, and are termed epiphyses until they are finally joined to the main part, after which they receive the name of *apophyses.*

Ossification generally extends in the direction that the future laminæ and Haversian rods are to assume, and which corresponds in a great measure to that in which it is designed that the chief strength of the structure may lie. Thus, in the bones composing the vault of the cranium, there is always a very decided radiation from the most prominent part of the convexity of each. In the scapula this direction is indicated by the lines of shading in the accompanying figure. The outline marks the limits of the temporary cartilage, in which no other points of bone have yet appeared.

Fig. 29.

Scapula of a fœtus at the seventh month; shewing the progress of ossification. Natural size. The light parts are epiphyses as yet cartilaginous —From the Museum of King's College, London.

The minute history of the process by which temporary cartilage is converted into bone, is of extreme interest. Very good descriptions of it have been given by Sharpey, Miescher, and others; from which, however, it will be seen by the following account that we differ in some important particulars.

The nucleated cells of temporary cartilage are small, and pretty uniformly scattered through a sparing, homogenous intercellular substance. The nuclei are granular, and large compared with the cells, which are distinguished from the surrounding substance

Fig. 30.

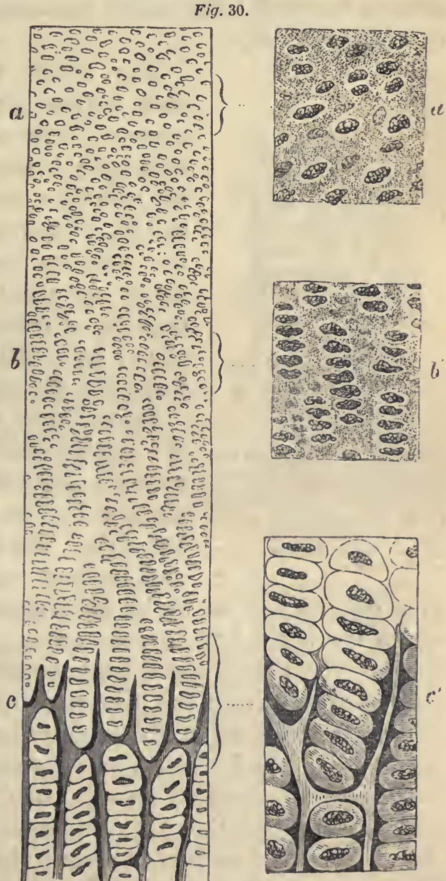
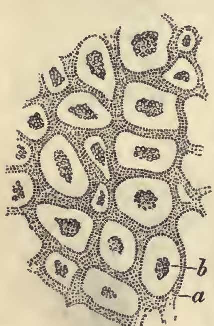


Fig. 30. Vertical section of cartilage near the surface of ossification:—*a*. Ordinary appearance of the temporary cartilage. *a'*. Portion of the same more highly magnified. *b*. The cells beginning to assume the linear direction. *b'*. Portion more magnified. Opposite *c*, the ossification is extending in the intercellular spaces, and the rows of cells are seen resting in the cavities so formed; the nuclei being more separated than above. *c'*. Portion of the same more highly magnified.— From a newborn rabbit which had been preserved in spirit.

principally by their transparency around each nucleus (fig. 30, *a. a′*).

In the vicinity of the point of ossification for example, in one of the long bones), a singular change is observed. The cells are seen to be gradually arranging themselves in linear series, which run down, as it were, towards the ossifying surface. The appearance they present on a vertical section is represented in fig. 30. At first their aggregation is irregular, and the series small (*b. b′.*); but, nearer to the surface of ossification, they form rows of twenty or thirty. These rows are slightly undulated, and are separated from one another by the intercellular substance. The cells composing them are closely applied to one another, and compressed, so that even their nuclei seem in many instances to touch: the nuclei themselves are also flattened, and expanded laterally.

Fig. 31.



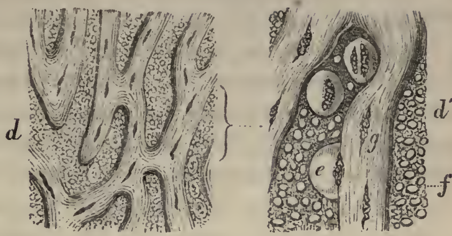
Horizontal section at the ossifying surface of a fœtal bone; shewing the cups of bone cut across, with the granular nuclei of the included cells. *a.* New bone. *b.* Nucleus.—From the rabbit. Taken from a drawing of Mr. Tomes.

The lowest row dip into, and rest in deep narrow cups of bone, formed by the osseous transformation of the intercellular substance between the rows. These cups are seen by a vertical section in fig. 30, *c. c′.*, and by a transverse section on the level of the ossifying surface in fig. 31. As ossification advances between the rows, these cups are of course converted into closed areolæ of bone, the walls of which are lamelliform, and at first extremely thin.

Immediately upon the ossifying surface, the nuclei, which were before closely compressed, separate considerably from one another by the increase of material within the cells. The nuclei likewise often enlarge and become more transparent; a condition first pointed out to us by Mr. Tomes, but not present in fig. 31, which was taken from a preparation that had been immersed in spirit. The changes now enumerated may be conveniently considered to constitute the *first stage* of the process, which extends only to the ossification of the intercellular substance. In this stage there are no blood-vessels directly concerned.

The areolæ or minute *cancelli*, when first formed, contain only the rows of cells which they have enclosed. It is remarkable, that, when the cartilage is torn from the bone, it usually carries with it one or two layers of these cancelli, or a little more than is represented in fig. 30. If the specimen be examined deeper in the bone, even at a depth of $\frac{1}{8}$ or $\frac{1}{10}$ of an inch, other appearances are met with. The lamellæ of bone enclosing the cancelli are no longer simply homogenous or finely granular in texture, but have acquired more the aspect of perfect bone. They are also thicker, and include in their substance elongated oval spaces, which, excepting that they are of a roughly granular nature, exactly resemble the *lacunæ* of bone already described. They are evidently the *nuclei* of the cells of the temporary cartilage. They are scattered at pretty uniform distances apart, and they all follow the direction of the lamellæ to which they belong (fig. 32, *d*, *g*). The curvilinear outline of their now ossified cells can often be partially discerned (fig. 32, *e*).

Fig. 32.



Vertical section from the same specimen as fig. 30, but deeper in the bone, shewing the cancelli with blastema and a few cartilage-cells, and also the osseous laminæ containing lacunæ, similar to the nuclei of the cells:—*d.* Seen by a low power. *d′.* Portion of *d* more highly magnified. *f.* Blastema around the cartilage-cells. *e.* Cartilage-cell apposed to the wall, and its nucleus ready to become similar to the other lacunæ, as *g.*

Within the cancelli, only a few cells can be detected, these cavities being chiefly occupied by a quantity of new substance, consisting of granules, and resembling a formative *blastema* or basis, like that out of which all the tissues are evolved (fig. 32, *f*, and fig. 33, *i*). The cells that are met with are in apposition with the wall; and sometimes (as in fig. 32, *e*) one of them seems half ossified, and its nucleus about to become a lacuna. The nuclei of these cells have now always the same direction as the neighbouring lacunæ.

*Fig.*33.

Another portion from the same specimen:—*i. i. i.* Portion of three cancelli, containing blastema, and having between them the wall of bone. The interior of this wall, *l*, is finely granular, and contains no lacunæ, being the lamina first formed between the rows of cells in the cartilage. Coating this on both sides is a layer of bone in which the form of the cartilage-cells is still visible, as well as their nuclei forming the lacunæ. On the wall of the cancellus on the right are seen two nuclei, which appear to be forming there. This last is an appearance often seen.

In fig. 33, taken from a little deeper in the bone, we have portions of three cancelli, *i. i. i.*, together with the osseous material, now of considerable thickness, that intervenes between them. In the centre of this last is seen a lamella, *l*, of a peculiar kind, containing no lacunæ, and quite distinct from the layers, *h. h.*, between which it lies. These consist of nucleated cells corresponding in size with those of the temporary cartilage, and having their nuclei disposed vertically, and of the same shape and dimensions as the lacunæ of bone. They are still granular, however, and no pores can be seen emerging from them. The cells are united together, and the lines of their junction have for the most part disappeared. The curvilinear border of each can be still seen, however, at its union with the central lamina, *l.* In the cancelli, *i. i. i.*, the granular blastema exists in great abundance.

It hence appears, that, after the ossification of the intercellular substance the rows of cartilage-cells arrange themselves on the inner surface of the newly formed cancelli, and become ossified, with the exception of their nuclei, which remain granular, and subsequently form the lacunæ of bone; and that a new substance, or blastema, appears within the cancelli, from which, probably, vessels are developed, and the future steps in the growth of the bone proceed.

The cancelli when first formed are closed cavities. At a subsequent period they appear to communicate, and thus to form the cancelli and Haversian canals of perfect bone; a complete network of blood-vessels becoming developed within them at the same time.

The subsequent progress of ossification seems to consist essentially of a slow repetition, on the entire vascular surface of the bone, of that process which has been now briefly described. It is probable that new cartilage-cells are developed on that surface, and become ossified in successive layers, their nuclei remaining to form the lacunæ, the uniform dispersion of which through bone is thus explained. The cause of the *lamination* of bone, parallel to its vascular surface, is also thus illustrated.

The first appearance of pores is in the form of irregularities in the margin of the lacunæ. These increase with the consolidation of the tissue, and are converted into branching tubules which communicate with those adjacent. These pores must consequently be formed in the ossified substance of the cartilage-cells. In our account of the lacunæ of perfect bone it was mentioned, that, for the most part, those of contiguous Haversian systems do not communicate across the narrow interval that separates the Haversian rods; this interval having, in fact, no pores. It results from what has just been said of the mode of deposition of new layers, that the primary osseous network, formed in the intercellular substance of the temporary cartilage, must come to constitute the substance intervening between the Haversian rods, the non-porosity of which is thus satisfactorily accounted for, as well as the facility with which the rods themselves may be made to separate from one another. As for the lacunæ, their originally granular interior seems to be gradually removed, so that they become vacuities adapted for the conveyance of the nutritious fluids through the compact material of the perfect bone.

Growth of Bone.—But it must not be imagined, that, when bone is once deposited in a certain form, it thenceforward permanently maintains its size and shape. Though a lamella be completely ossified, its particles are in constant course of change, during which the most important and extensive alterations of size and figure take place in a slow and gradual manner. Thus the layers first deposited on the inner surface of the early cancelli are pushed out by the succeeding ones, and also acquire a concomitant augmentation of mass; and as, in general terms, the number of lacunæ in bone is proportioned to its amount, the early layers most likely increase by a growth and ossification of cells in their own substance, even for long after they had been pushed away from the vascular surface, and supplanted by the more recent ones. Thus, though bone grows chiefly by layers formed in succession on its vascular surface, yet it also grows in an interstitial manner after being originally deposited. It is in this way only that we can explain the great expansion which the primary intercellular osseous network must undergo, to form that which intervenes between the Haversian systems.

Bone when first formed, then, is disposed as an expanded surface, variously and complexly involuted, and which soon becomes covered with vessels. This is the foundation for its subsequent vascularity, and is the source also of that active power of internal growth, which has been long a theme of admiration with physiologists.

But the expansion of bone once deposited is limited. We before observed that no part of the osseous tissue was at more than a certain minute distance from the vascular surface; and that, if it were so, its nutrition could not be suitably carried on. Now, if more than a certain number of laminæ of new bone were laid down, the earlier ones would be pushed too far from the supply of blood; and hence the limitation we have spoken of. But it is necessary for bone to grow much more between the commencement of ossification and the adult age than this limitation appears to allow of; and here we come upon an admirable provision to meet this apparent difficulty.

In the *first* place, a most important process of growth is continually going on *in the cartilage*, especially near the ossifying surface, by the multiplication of the cells; and, in the latter situation, by the increase in their dimensions, occasioning that separation of their nuclei, already described (p. 118, and fig. 30, *c*). In the long bones this takes place chiefly in the longitudinal direction, which is that in which growth is most active; and it continues till adult age. This fact has been long ascertained, though its real purpose appears to have been overlooked. Hales and Hunter both inserted metallic substances along the shaft of a growing bone, in a young animal, at a certain distance apart; and found, after an interval of time, that the distance between them remained the same, or nearly so, while the extremities of the bone were much further apart: thus proving that the principal growth had taken place near the extremities.

Secondly, bones increase in dimension by an accession of new *osseous* substance on their exterior; this new substance consisting not merely of new laminæ, but of new systems of laminæ, and of new involutions of the vascular surface to form new Haversian canals, so that the earlier systems of laminæ are covered over by the more recent ones. This has been best proved by the experiments with madder.

It was ascertained accidentally by Belchier that the rubia tinctorum, or madder, mixed with the food of pigs, imparted its red colour to their bones; and this circumstance has been ingeniously taken advantage of by several physiologists in the prosecution of researches on the growth of bone.* Duhamel, Hunter, and many others, have performed multiplied experiments of this kind. In the Museum of King's College are some good preparations of bones so acted upon.

It is found that, in very young animals, a single day suffices to colour the entire skeleton, apparently in an uniform manner; in these there is no osseous material far from the vascular surface. But, if we make a transverse section of one of the long bones so treated, we observe the deepest, or even the only colour, to be really on the vascular surface; the Haversian canals are each

* The colouring of bone by madder results from an affinity of the colouring principle for the phosphate of lime. This opinion was distinctly broached by Haller (El. Phys. t. viii. p. 329), and it was subsequently proved by Rutherford, who shewed it experimentally. To an infusion of madder in distilled water add muriate of lime: no change takes place. Then add phosphate of soda in solution. By double elective affinity, phosphate of lime and muriate of soda are formed. The phosphate is insoluble, and subsides in union with the colouring matter as a crimson lake. When madder is given as food, its colouring principle is absorbed, and circulates with the blood; and it colours first that part of the bone which is in course of formation from that fluid, or which has been last formed, *i. e.* which is nearest the vascular surface.

encircled by a crimson ring. This beautiful illustration is due, as far as we know, to Mr. Tomes, who has long possessed some very elegant specimens prepared in this way.

In full-grown animals the bones are very slowly tinged, because the great mass of the bone is not in contact with blood-vessels; each Haversian system, for example, has only its small innermost lamella in contact with them; and, besides, the osseous matter is altogether more consolidated and less permeable by fluids than at a very early period of life. In the bones of half-grown animals a part of the bone is nearly in the perfect condition, while a part is new and easily coloured. Hence, it is easy in them to distinguish the new from the old by means of madder.

Now, madder given to half-grown animals colours the long bones most deeply in the interval between the shaft and extremities, and on the surface of the shaft. When madder is given at intervals, the tints in the bone are interrupted; the layers in course of formation during its administration are coloured, while those formed during the intervening periods are colourless. The long period during which bones retain the madder tinge, shews that the colouring matter is not readily resumed by the blood, from its combination with the phosphate of lime; and it seems also to indicate a sluggishness of the nutrient process in bone.

Perhaps few questions have more divided the minds of physiologists than that regarding the share taken by the periosteum in the growth and regeneration of bone; for these last are essentially the same process. We now see that bone does not grow on its exterior because the periosteum is there; and that the only part this membrane takes in the deposit of new bone is by the vascular network mingled with its fibrous tissue, and which does not differ from that on other portions of the osseous surface.

The limited expansibility of the bone already formed is the remote cause to which the growth by new deposit on the exterior is to be referred; and, in this respect, the superficial growth is strictly analogous to the exogenous mode of growth in vegetable structures.

A third mode in which increase of size is provided for, appears to be by the dilatation of the primary cancelli and Haversian canals in the central parts of the bone. In early life the cancelli are small, and there is no medullary cavity. Gradually the cancelli enlarge, and those within the shaft blend more and more with one another, by the removal to a greater or less extent of the intervening osseous walls, until at length a medullary canal is formed, around which the cancelli are very open, large, and irregular. This augmentation of the vascular cavities of bone is attended with a development of adipose vesicles and their capillaries in the new space, while the proper vessels of the osseous tissue remain pretty much as before. The fat contained in the medullary canal gradually accumulates so much, that a special artery becomes enlarged to supply it, assuming the very inappropriate title of "*the* nutrient artery of the *bone*." Duhamel placed a ring of silver round a bone of a young pigeon, without injuring the periosteum. After some time, during which the bone had increased in diameter, he found the ring in the medullary canal, which had acquired a capacity equal to the previous diameter of the whole shaft.

This enlargement of the diameter of a long bone by the dilatation of its interior, is attended by two consequences, equally important. The shell of compact tissue is thus adapted to offer greater resistance to injurious mechanical forces, while the disadvantage of a corresponding increase of weight is obviated.

Reparation of Bone.—The great importance of this subject to the surgeon has led to many very interesting researches from the time of Duhamel to the present day, and by these the several steps of the process by which new bone is deposited have been ably elucidated in all that relates to their more obvious characters. When a fracture occurs, blood is, of course, effused into the wound, both from the ruptured vessels of the bone itself, and from those of the surrounding structures participating in the injury. At a short period subsequently, a semi-transparent lymph is found mingled with the coagulum, and covering the surfaces of the hard and soft parts exposed. This lymph in all probability is the same as that by which the adhesive process in other wounds is effected. In the second and third weeks a gradual condensation of this takes place, accompanied with an interstitial change, converting it into a substance resembling temporary cartilage.

Ossification takes place throughout this in a nearly uniform manner, until, towards the fourth or sixth week, the whole is transformed into a spongy, but firm osseous mass, investing the exterior of the broken extremities, and extending between them in the form of a case, by which they are firmly held together. If the medullary canal has been broken across, and the broken ends evenly adjusted, there will be likewise an interior stem of new bone connecting the medullary canal of the fragments in the axis of the bone; the opposed surfaces of the compact tissue being as yet ununited. The *callus*, or new bone, thus formed, was termed by Dupuytren *provi-*

sional, as it is gradually absorbed during the succeeding months, while the *permanent* callus is being slowly deposited between the contiguous surfaces of the compact tissue. It would appear that new bone is formed more exuberantly in the situations of the provisional callus because of their greater vascularity; just as we may suppose the function of ordinary nutrition to be more active in those parts, than in the compact tissue of the bone. The permanent callus has all the characters of true bone.

When the reparative process in bone is interfered with, either by mal-apposition of the fragments, or by constitutional fault, a spurious union may occur by the medium of a ligamentous substance, or even a diarthrodial joint may be formed at the seat of fracture. The ends of the bones become altered in form, and adapted to one another; a kind of false capsular ligament is developed, and sometimes even an imperfect cartilage, and a lining membrane furnishing a lubricating fluid.

The following works may be consulted on Bone:—The systems of General Anatomy already quoted (p. 87); Meckel, Anat. Générale Descript. et Patholog., tom. i.; Dr. Bostock's Physiology, where will be found an excellent and learned summary of the observations of preceding physiologists on the structure and growth of bone; Mr. Paget's paper on the influence of Madder on the Bones of growing Animals, Lond. Med. Gazette, vol. xxv.: Deutsch, de penitiori Ossium structurâ observationes; 1834: Miescher, de inflammatione Ossium eorumque anatome generali; 1836: Müller's Physiology by Baly, vol. i. M. Flourens has lately published a handsome volume on the growth of bone, illustrated with figures.

CHAPTER VI.

SYNOVIAL MEMBRANES.—SEROUS MEMBRANES.—VARIETIES OF JOINTS —MECHANISM OF THE SKELETON.

The different forms of bones, when united according to various mechanical contrivances, constitute the skeleton. The framework of the body, being thus formed of several pieces jointed together, is admirably arranged for extended, or for minute and nicely adjusted motions, and for distributing concussions over a large surface. The interposition of discs, or laminæ, of elastic cartilage, or fibro-cartilage, between some bones, contributes to the latter object, by interrupting the medium through which the shock would be conducted, as well as by the elasticity of the intervening substances; and, at the same time, these discs, by their intimate adhesion to the opposed osseous surfaces, serve as powerful bonds of union between them. Joints of this kind (*synarthrodial*) enjoy a very limited degree of motion, which is entirely due to the yielding and elastic nature of the interposed material. When a greater range of motion is required than can be obtained in this way, the surfaces of the osseous segments are constructed so as to glide the one upon the other in certain directions, which are determined by the form of the articular surfaces, and by the positions at which the connecting ligaments are placed. Here the bond of union consists of the ligaments and the surrounding muscles; the osseous segments are not, as in the former instance, continuous with each other through the interposed texture, but are separated by a space which is called the *cavity of the joint*. Each osseous surface is encrusted by a layer of articular cartilage adapted to its form, and the cavity of the joint is lined by a delicate membrane, which secretes a peculiar viscid matter, *synovia*, admirably suited to lubricate the surface. This membrane is termed *synovial*, and is constantly present in the *diarthrodial* joints.

The *articular synovial membrane* forms a closed bag, placed between the articular surfaces of the bones. Its free surface is smooth and moist; its attached surface adheres by very fine areolar tissue to the ligaments of the joint, and to the cartilages encrusting the extremities of the bones. From the ligaments it may be readily detached, and traced to the edge of the cartilage; to this it is very intimately adherent for some little distance, beyond which it cannot be followed where the cartilage has been exposed to pressure during the motions of the joint. In the fœtus it is continued over the whole cartilage (p. 90).

In some of the more complex joints the synovial membrane forms folds, which project more or less into the articular cavities, and contain fat, which Clopton Havers and other anatomists erroneously imagined to perform a glandular office, and to secrete the synovia. The knee affords some remarkable examples of these folds, in what are known as the alar ligaments.

A great number of blood-vessels are distributed in the areolar tissue upon the attached surface of the synovial membrane. In inflammation, the membrane acquires a red hue by the repletion of these vessels, and in a minute injection also it becomes coloured. Excepting in very rare cases, the vessels cannot be traced beyond the edge of the cartilage, where they form a series of loops. (See page 93).

Bursæ.—A very simple form of synovial membrane is employed to facilitate the gliding of a tendon, or of the integument, over an osseous projection. It consists of a bag, generally closed at every point, connected by areolar tissue with the neighbouring parts, and secreting into its interior fluid, which lubricates its free surface. Sometimes, when one of these bursæ exists in the neighbourhood of a large joint, it communicates freely with the cavity of its synovial membrane, as in the bursa behind the rectus femoris above the knee-joint, and that near the hip-joint behind the tendon of the psoas and iliacus muscles. These synovial sacs are found in great numbers throughout the body: some are superficial, or *subcutaneous,* such as that between the skin and the patella, or that over the great trochanter of the femur, or that over the olecranon: the *deep-seated* bursæ, however, constitute the largest proportion of them; these are almost always connected with tendons, and interposed between them and the bones over which they play. On opening a bursa, we often find its cavity traversed by bands, which are either congenital, and approaching to the cellular or areolar disposition, or, as seems not unlikely, of the nature of adhesions, and consequently a morbid production tending to the obliteration of its cavity.

Synovial Sheaths.—These are synovial bags prolonged into the form of sheaths, and surrounding long tendons, such as those of the flexor or extensor muscles of the fingers and toes, as they lie in their osseo-fibrous sheaths in the hand or foot. One layer of the synovial sheath adheres to the wall of the osseo-fibrous canal; the other, to the contained tendon; and, the free surface being lubricated by synovia, the tendon plays freely within the canal. In deep-seated whitlow, when the inflammation extends to one of these synovial sheaths, and gives rise to the formation of adhesions within its cavity, the motion of the tendon within is completely destroyed, and a stiff finger is the result. Similar sheaths on a larger scale envelope the tendons which pass beneath the annular ligaments of the wrist and ankle.

Synovia.—The synovial membranes, in health, contain only sufficient fluid to keep their free surfaces moist. It is, therefore, difficult to collect the synovia in sufficient quantity for examination. It is a transparent, yellowish-white fluid, viscid like the white of an egg, whence its name (*συν, cum; ωον, ovum*). Lassaigne and Boissel, who have published an analysis of human synovia, state that it does not coagulate spontaneously; that it is an alkaline fluid, containing albumen and salts, such as are found in the serum of the blood: and M. L'Heritier has lately analysed two specimens of this fluid, and completely confirmed the statement of those chemists.*

It is plain, from the description above given, that synovial membranes contribute to the locomotive function by lubricating the articular surfaces, so that they may glide smoothly on one another with the least possible friction, and also by facilitating the play of some tendons over prominent surfaces, and of others within sheaths.

Serous Membranes.—The movements of the viscera within the great cavities of the trunk are provided for by an arrangement similar to that described in the joints. Between the wall of the cavity and the surface of the contained viscus (the thorax and the lungs, for example,) a closed sac is placed, one layer of which is *parietal*, and the other *visceral*. These are respectively attached to the wall of the cavity and to the surface of the viscus by fine areolar tissue; and their continuity is shewn at certain reflections where the one passes into the other. The free surface, as in the synovial membranes, is continually moistened by the proper secretion, which, containing a larger proportion of water than synovia does, resembles serum of blood. The serous membranes are, the arachnoid, in the head and spine; the pleura and pericardium, in the thorax: the peritoneum, in the abdomen; and the tunica vaginalis testis, in the

* Berzelius Chemie Organ. t. vii.

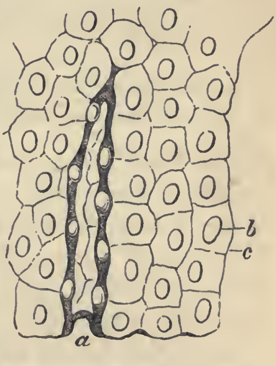
scrotum. These are all closed at every point; so that their secretion, if morbidly increased, is retained within the cavity, and can only be removed by absorption, or by an opening through the membrane. In the healthy state, the surfaces are only moistened; and, when more fluid exists, it is the product of disease, or of post-mortem change. If the surfaces be dry, or a viscid adherent matter be effused upon them, the movements of the contained organ become impeded, and are accompanied by a peculiar sound of friction, and a vibration sensible to the hand; both of which are well known to physicians in the pericardium, pleura, and peritoneum, and may frequently be noticed by the patients themselves.

The peritoneum of the female affords a remarkable exception to the closed character of serous sacs. At two points this membrane is open, where it communicates with the canal of each Fallopian tube at its dilated extremity.

The blood-vessels of serous membranes are distributed in considerable numbers in the areolar tissue which is connected with their attached surface. We infer that nerves exist freely in the same tissue, from the intense pain which accompanies inflammation of these membranes. There is good reason to believe that lymphatics also are freely distributed in their areolar tissue.

The serous membranes connect the viscera contained in the cavities to which they respectively belong, by the folds they form as they pass from each viscus to the wall of the cavity. As the viscera in the abdomen are so many, and the folds proportionately numerous, the peritoneum is more complicated in its disposition than any other serous membrane; and it is part of the study of the descriptive anatomist to shew, that the remarkable complication of folds which this membrane exhibits is not inconsistent with its adherence to the chief morphological character of serous membranes.

Fig. 34.

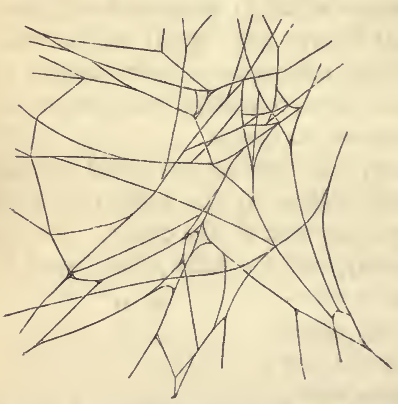


Epithelium of serous membrane:—At *a*, an accidental fold is represented, the two dark edges of which exhibit the thickness of the particles, and of their nuclei. *b*. One of the oval nuclei. *c*. Line of junction between two particles.—Magnified 300 diameters.

Microscopic Characters of Synovial and Serous Membranes.—These membranes appear to be essentially alike in their minute structure. On their free surface is a single layer of *epithelium*, the particles of which are polygonal in shape, and of transparent texture. A small fragment of this pavement, from the peritoneum of the rabbit, is represented in fig. 34. This was discovered, by Henle. We have found this epithelium to rest immediately on a continuous transparent *basement membrane* of excessive tenuity, apparently identical with that which supports the epithelium of mucous membranes. Beneath this is a lamina of *areolar tissue,* which constitutes the chief thickness of the membrane, and confers on it its strength and elasticity. This areolar tissue is traversed by a network of capillary vessels, the meshes of which are large and of rather unequal size, and by lymphatics and nervous filaments in varying number. It is of close texture, and continuous with that laxer variety by which the membrane is attached to the parts it lines.

The most favourable position for examining the areolar tissue of serous membrane, is the transparent part of the mesentery, or of any of the duplicatures of the peritoneum, in small animals.

Fig. 35.



Yellow fibrous element of the areolar tissue of serous membrane. From the mesentery of the Rabbit, treated with acetic acid.—Magnified 300 diameters.

Here we observe the yellow fibrous element assuming a very beautiful arrangement (fig. 35). Its filaments interlace and inosculate chiefly in a plane beneath the basement membrane, in such a manner as to confer equal elasticity in every direction. The intermediate space is occupied by the white fibrous element disposed in wavy bands, variously intersecting, and which become straight only when the elastic threads are stretched.

Physical and vital Properties. — These are precisely those of areolar tissue: the elasticity of the serous membranes is very considerable, owing to the admixture of the yellow fibrous element in the layer which forms the chief substance of the membrane. These tissues are entirely devoid of vital contractility; and their sensibility is low, except in a state of acute inflammation.

These membranes exhibit, in their inflamed state, a remarkable tendency to throw out lymph on their interior, so as to cause adhesion of their opposed surfaces. Hence a frequent result of inflammation of a serous membrane is the obliteration, to a greater or less extent, of its cavity. Synovial membranes are not so prone to the adhesive inflammation as the serous are, which seems more to be accounted for by the nature of their secretion, than by any difference of their structure. The proneness of these membranes to the effusion of coagulable lymph seems to be due to the extreme tenuity of the layer of epithelium which separates the nutrient blood-vessels from the cavity of the serous membrane. The lymph effused becomes gradually converted into areolar tissue and vessels, usually constituting what are termed adhesions, but sometimes forming merely a thickened condition of the membrane.

Of the Joints.—A joint, or articulation, may be defined to be the union of any two segments of an animal body, through the intervention of a structure or structures different from both.

The most perfect and elaborate forms of the articulations are those which are seen in animals that possess a fully developed internal skeleton, and in none may they be studied with more advantage than in man. In the human subject, and in the vertebrated animals generally, we have, indeed, particular occasion to admire the articulations as "mirabiles commissuras, et ad stabilitatem aptas et ad artus finiendos accommodatas, et ad motum, et ad omnem corporis actionem."

The textures which form the joints, are bone, cartilage, fibrocartilage, ligaments, synovial membrane. Bone constitutes the fundamental part of all joints; ligament variously modified is employed in all as a bond of union; but the three remaining textures are present chiefly in those joints which enjoy a free gliding motion.

In addition to the structures already named as entering intrinsically into the formation of joints, we find that the tendons and muscles, which lie in the immediate vicinity of or which surround the joints, contribute much to their strength and security. In joints of the hinge kind we generally see the anterior and posterior parts protected more or less by the tendons of muscles, and even by muscles themselves passing from one segment of a limb to another; and here it frequently happens, that the tendon is bound down on the bones which form the member, by a fibrous expansion of great strength, lined by a synovial membrane of the same characters as the articular, but adapted in its form to the osseo-fibrous canal in which the tendon is placed, *e.g.* the tendons of the fingers. The protection and strength afforded by muscles is particularly evinced in the case of the shoulder-joint, where the capsular ligament is closely embraced by four muscles, whose tendons become identified with the fibrous capsule as they go to be inserted into the bone.

A muscular capsule is thus provided for the joint, by which the bones are maintained much more firmly and powerfully in apposition than they would be if kept together by an uncontractile ligamentous capsule alone; hence the elongation of the arm that occurs as a consequence of paralysis, and hence also the greater liability to luxation which exists in a debilitated state of the system. Articular or capsular muscles thus placed, have also the effect, as it is said, of preventing the pinching of the capsule or synovial membrane between the articular extremities of the bones in the different motions of the joint.

Atmospheric pressure, exerting as it does a force of nearly fifteen pounds on the square inch, is a powerful agent in maintaining the contact of articular surfaces. This is well illustrated by the difficulty of separating the surfaces composing the hip and shoulder joints, when the surrounding ligaments are air-tight; while, on the other hand, these surfaces may be separated by the mere weight of either bone, if one of these joints be suspended in the exhausted receiver of an air-pump. In exhibiting this experiment, we find the shoulder joint shews the effects of atmospheric pressure more strikingly than the hip, for its capsule being loose, and the osseous cavity for the reception of the head of the humerus small, the pressure of the atmosphere pushes in the capsule, so that it fits closely to the head of the bone. When this pressure has been removed by exhausting the receiver, the head of the humerus falls rapidly from the socket, and the ligament becomes stretched by the weight of the bone.

The joints are supplied copiously with blood, and are remarkable for the arterial anastomoses which take place about them. The best examples of these inosculations are met with around the large joints of the extremities. The parts supplied with blood are the synovial membranes, the ligaments, the fat, and the extremities of the bone; but the cartilages certainly do not contain blood-vessels.

Of the Forms and Classification of the Joints.—It is not difficult, by passing in review the various motions which take place between any two segments of a limb, to form an idea, *à priori*, as to the kinds and shapes of the articulations by which these segments will be united; it is only necessary not to lose sight of the fact, that in the construction of a joint, regard is had not to its mobility alone, but to its security, its durability, and the safety of the neighbouring parts. We may expect to find joints varying in the *degree* of motion, from the slightest perceptible, to the freest that is compatible with the maintenance of the segments in their proper relation with each other; and also in *extent* of motion, from that which is so slight as to admit of almost no appreciable change in the position of the parts, to that which allows of the most ample variety of movement between the segments, consistent with the integrity of the articulation.

It will appear, then, that the most simple kind of articulation is that by which two parts are so united as that only the slightest appreciable degree of motion shall exist between them. This constitutes the first great division of joints — the *Synarthrosis,* where the parts are continuous, *i.e.,* not separated from each other by an intervening synovial cavity. Some anatomists consider all synarthrodial joints to be immovable; which, although not far from the truth, cannot be said to be strictly accurate. Had immobility been the object to be attained, that might have been more effectually accomplished by the fusion of the extremities of the segments together, as in anchylosis.

In the second class of joints, motion is enjoyed freely and fully: this class is designated by the term *Diarthrosis:* the segments are interrupted completely in their continuity; the extremities of the bones can only be said to be contiguous.

Synarthrosis.—The general characters of the articulations belonging to this class are, 1, that they are very limited in their motion, insomuch as to be considered by some as immovable; 2, that their surfaces are continuous, *i. e.,* without the intervention of a synovial cavity, but with that of some structure different from bone. The following varieties may be noticed among synarthrodial articulations.

a. Suture.— When the margins of two bones exhibit a series of processes and indentations (dovetailing) which are received and receive reciprocally, with a very thin cartilaginous lamina interposed, this is the ordinary kind of suture, *sutura vera,* of which three kinds are distinguished: *sutura dentata,* where the processes are long and dentiform, as in the interparietal suture of the human skull; *sutura serrata,* when the indentations and processes are small and fine, like the teeth of a saw, as in the suture between the two portions of the frontal bone; *sutura limbosa,* when there is along with the dentated margins a degree of bevelling of one, so that one bone rests on the other, as in the occipito-parietal suture.

When the two bones are in juxta-position by plain but rough surfaces, the articulation is likewise said to be by suture, and this is the false suture, *sutura notha,* of which there are two kinds; *sutura* *squamosa,* where the bevelled edge of one bone overlaps and rests upon the other, as in the temporo-parietal suture, and *harmonia* (*αρω, adapto*), where there is a simple apposition: this last kind of articulation is met with, as Bichat observes, wherever the mechanism of the parts is alone sufficient to maintain them in their proper situation, as may be seen in the union of most of the bones of the face.

The sutures have a considerable tendency to become obliterated by age, the intervening cartilage becoming ossified; it rarely happens that the sutures are all manifest in a human skull past fifty years of age, and sometimes the obliteration takes place at a much earlier period. The frontal suture is by no means permanent; it is not often found at puberty. In birds and fishes this tendency to the obliteration of the sutures is particularly manifest.

b. Schindylesis (*σχινδυλησις, fissio; σχιζω, diffindo*).—This form of articulation is where a thin plate of bone is received into a space or cleft formed by the separation of two laminæ of another, as is seen in the insertion of the azygos process of the sphenoid bone into the fissure on the superior margin of the vomer; and in the articulation of the lachrymal bone with the ascending process of the superior maxillary.

c. Gomphosis (*γομφος, clavus. Clavatio, conclavatio*). When a bone is inserted into a cavity in another, as a nail is driven into a board, or as a tree is inserted into the earth by its roots, the articulation is by gomphosis. The only example we have of it in the human subject, or in quadrupeds, is in the insertion of the teeth into the alveoli.

d. Amphiarthrosis.—This is a form of articulation where two plane, or mutually adapted surfaces are held together by a cartilaginous or fibro-cartilaginous lamina of considerable thickness, as well as by external ligaments. In virtue of the elasticity of the interposed cartilaginous or fibro-cartilaginous lamina, the amphiarthrosis possesses a manifest, although certainly a very limited degree of motion, and hence most systematic writers class it with the diarthrodial articulations. But it appears much more consistent to place it among the synarthrodial joints, for, 1, its anatomical characters agree precisely with those of synarthrosis; 2, the surfaces in amphiarthrosis being continuous, it would make an exception in diarthrosis were we to place it there; and, 3, its degree of motion is greater than that of suture, only because of the greater development of the interosseous substance.

The examples of this form of joint in the human body are, the articulation between the bodies of the vertebræ, that between the two ossa pubis at what is called the symphysis, and that between the ilium and sacrum. Like the sutures, the amphiarthroses are liable to become obliterated in old age, by the ossification of the interosseous lamina. This is not common in the interpubic, and occurs now and then in the intervertebral and sacro-iliac joints.

Diarthrosis.— Mobility is the distinguishing characteristic of this class of joints; the articular surfaces are *contiguous*, each covered by a lamina of cartilage (*diarthrodial cartilage*), having a synovial sac interposed, and in some cases two, separated by a meniscus. The integrity of the articulation is maintained by ligaments which pass from one bone to the other. Their mechanism is much more complicated than that of synarthrodial joints, being intended not only for security, but also to give a certain direction to the motions of which they are the centre.

Before proceeding to the enumeration of the varieties of joints that come under this head, it will not be amiss to describe briefly the various motions which may take place between any two segments of a limb, and which it is the object of these joints to admit of. It is obvious, that the most simple kind of motion which can exist between two plane or contiguous surfaces, is that of *gliding:* one surface glides over the other, limited by the ligaments which extend between the bones. This motion, however, is not confined to plane surfaces; it may exist evidently between contiguous surfaces, whatever their form. When two segments of a limb, placed in a direct line, or nearly so, can be brought to form an angle with each other, the motion is that of *flexion*, the restoration to the direct line is *extension.* These two motions belong to what Bichat calls *limited opposition;* the flexion and extension of the fore-arm on the arm illustrate it. Sometimes a motion of this kind takes place in four directions, indicated by two lines which cut at right angles. This is best understood by a reference to the motions which take place at the hip-joint: there it will be seen that the thigh-bone may be brought forward so as to form an angle with the trunk, *flexion*— or it may be restored, *extension;* it may be separated from the middle line of the body so as to form an angle with the lateral surface of the trunk, *abduction*— or it may be restored and made to approximate the middle line, *adduction.* It is evident that a joint, which is susceptible of these four motions, may also move in the intermediate directions. When these motions are performed rapidly, one after the other, one continuous motion appears, in which the distal extremity of the bone describes a circle indicating the base of a cone whose apex is the articular extremity moving in the joint; this motion is called *circumduction.*

Rotation is simply the revolving of a bone around its axis. It is important to bear this definition in mind: through losing sight of it, many anatomists have attributed rotation to a joint which really does not possess it.

The varieties of the diarthrodial joint are as follows:

a. Arthrodia.— In this species the surfaces are plane, or one is slightly concave, and the other slightly convex: the motion is that of gliding, limited in extent and direction only by the ligaments of the joint, or by some process or processes connected with the bones. The examples in man are, the articular processes of the vertebræ, the radio-carpal, carpal, carpo-metacarpal, inferior radio-ulnar, superior tibio-fibular, tarsal and tarso-metatarsal, temporo-maxillary, acromio-clavicular, and sterno-clavicular joints. This last articulation and the wrist-joint possess a greater latitude of motion than the others; the former, in consequence of the shape of its articular surfaces; each surface is convex in one diameter and concave in the other, so that the gliding that takes place in this joint is in the direction of the long and short diameters, which intersect each other at right angles. It is capable, therefore, of vague opposition in those lines, but certainly not in the intermediate directions, the nature of the surfaces being calculated to prevent this. The wrist owes its mobility to the laxity of its ligaments, which permit it to move as well in its transverse as in its antero-posterior diameters, as also in the intermediate directions; it consequently admits of vague opposition and circumduction. The articulation of the metacarpal bone of the thumb with the trapezium is also an arthrodia very similar to the sterno-clavicular, but with a greater degree of motion. Arthrodial joints are generally provided with ligaments, placed at the extremities of the lines in the direction of which the gliding motion takes place.

b. Enarthrosis.— This is a highly developed arthrodia. The convex surface assumes a globular shape, and the concavity is so much deepened as to be cup-like; hence the appellation *ball and socket.* The ball is kept in apposition wtih the socket by means of a capsular ligament, which is sometimes strengthened by accessory fibres at certain parts that are likely to be much pressed upon. The best example of enarthrosis is the hip-joint, and next to it the shoulder: in the latter the cavity is but imperfectly developed. All the quadrupeds have their shoulder and hip-joints on this construction, and the same common plan is observed in the vertebrata generally whose extremities are developed. In birds and reptiles the bodies of the vertebræ are articulated by enarthrosis.

This species of joint is capable of motion of all kinds, opposition and circumduction being the most perfect, but rotation limited. Indeed, what is called rotation at the hip-joint, is effected by a gliding of the head of the femur from before backwards, and *vice versâ*, in the acetabulum; it is not a rotation of the head and neck, but of the shaft, of the femur.

c. Ginglymus (*γιγγλυμος, cardo*).—The articular surfaces in the hinge-joint are marked with elevations and depressions which exactly fit into each other, so as to restrict motion in all but one direction. They are always provided with strong lateral ligaments, which are the chief bonds of union of the articular surfaces.

The elbow and ankle joints in man are perfect ginglymi; the knee also belongs to this class, but is by no means a perfect specimen, for, in a certain position of the bones of this joint, the ligaments are so relaxed as to allow a slight rotation to take place. The phalangeal articulations, both of the fingers and toes, are ginglymi. This form of joint is most extensively employed among the lower animals. In quadrupeds, most of the joints of the extremities come under this head. In amphibia and reptiles, too, there are many examples of the hinge-joint. The bivalve shells of conchiferous mollusca are united by a very perfect hinge, and a great number of the joints of crustacea and insects are of this form.

The true ginglymus is only susceptible of limited opposition: hence the knee-joint cannot be regarded as a perfect example; in fact, in the perfect ginglymus there is every possible provision against lateral motion.

d. Diarthrosis rotatorius.—A pivot and a ring constitute the mechanism of this form of joint. The ring is generally formed partly of bone and partly of ligament, and sometimes moves on the pivot, sometimes the pivot moves in it. The motion is evidently confined to rotation, the axis of which is the axis of the pivot.

In the human subject the best example of this articulation is that between the atlas and odontoid process of the axis or vertebra dentata. The ring is formed by a portion of the anterior arch of the atlas, completed behind by a transverse ligament. Here the atlas rotates round the odontoid process, which is the axis of motion. Another example is the superior radio-ulnar articulation; here one-fourth of the ring is formed by bone, namely, the lesser sigmoid cavity of the ulna, and the remaining three-fourths by the round ligament called the coronary ligament of the radius. In this case there is rotation as perfect as in that just mentioned; but the head of the radius rolls in the ring, and the axis of motion is the axis of the head and neck of the bone. Some anatomists consider this joint a species of ginglymus, which they designate lateral.

The terms *Symphysis, Synchondrosis, Synneurosis, Syssarcosis, Meningosis,* have been employed by anatomists to designate certain kinds of articulation, chiefly in reference to the nature of the connecting media. Symphysis, although originally employed with great extent of meaning, seems to have been in later days applied exclusively to denote the articulations of the pelvis, which we have classed under Amphiarthrosis. We pass over the other terms, because they ought to be discarded from use, as only tending to encumber a vocabulary already too much crowded with difficult and unnecessary terms.

Mechanism of the Skeleton.—We shall conclude this chapter with some remarks upon the mechanical disposition of the various parts of the skeleton, and their adaptation to the purposes they were destined to fulfil.

The skeleton consists of the head, trunk, and extremities.

The head is composed of a cavity, surrounded by osseous walls (*cranium*), destined to contain and protect the brain; and of an expanded portion (*the face*), with which some of the organs of the senses are connected, and upon which the features are formed. The size of the cranium affords a good clue to determine the absolute size of the brain; and the proportion of the face to it, offers a not inexact index of the relation which the intellectual faculties and the animal propensities bear to each other.*

The spheroidal form of the cranium admirably adapts it for protecting the organ which it contains against external violence. The arched form is that which possesses most strength, and offers the greatest resistance. When, says Dr. Arnott, we reflect on the strength displayed by the arched film of an egg-shell, we need not wonder at the severity of the blows which the cranium can withstand. And he adds, in reference to the former, "what hard blows of the spoon or knife are often required to penetrate this wonderful defence of a dormant life!" And this form, which gives so much strength to the skull, favours the transmission of vibrations along its walls, and thus saves the delicate viscus enclosed by them. Thus blows inflicted upon the cranium become diffused; and sometimes

* See a good account of the comparative mensuration of the skull in Mr. Ward's Outlines of Human Osteology.

the violence applied directly to the vertex is spent upon the base of the skull, and causes a fracture there.

The compound structure of the cranial bones is an important element in the architecture of the skull as a protecting case to the brain. Most of these bones are formed of two tables: the outer one is tough, strong, and fibrous; the internal table is dense and brittle, and hence called *tabula vitrea;* and there is interposed between them a spongy texture, *the diploë*, in which blood-vessels are freely distributed (fig. 20, p.107). The varying density of these three layers evidently diminishes their power of conducting vibrations to the parts within, whilst it does not oppose the propagation of those vibrations in the direction of the layers themselves.

The manner in which the bones of the skull are united together has an evident reference to the physical properties of their inner and outer tables. The sutures are formed by the dovetailing of the outer table; the inner being cut straight, and simply placed in apposition (a layer of cartilage intervening), forming a sort of harmonia. The inner table, which is the brittle one, is not dovetailed, because its teeth would break readily; but the toughness and elasticity of the outer table fit it well for such a mechanism. On the same principle, Sir C. Bell remarks, a carpenter joins wood, which is tough and elastic, by tenon and mortise or by dovetailing; but, if pieces of glass or marble are to be joined, cement is employed for that purpose.

The principal part of the vault of the cranium is formed by the parietal bones, which rest upon the wings of the sphenoid, and upon the temporal bones: these overlap the lower borders of the parietal bones in such a way as to prevent them from starting outwards. They act on the principle of the tiebeam in the roofs of houses.

At certain exposed situations the bones experience a thickening of their structure, causing tuberosities, which are familiar to descriptive anatomists. These contribute to the strength of the roof of the skull: in front, in the frontal bone on each side of the middle line; laterally, in the parietal bones; and, behind, in the centre of the occipital bone. At this last situation two ribs, analogous to *groinings* in architecture, intersect each other: one extends from the centre of the frontal bone to the most projecting part of the occipital foramen; the other passes horizontally across the occipital bone, and terminates immediately behind the wedge-like processes which are formed by the petrous portions of the temporal bones. The occipital protuberance, which is the point of intersection of these groinings, is the "thickest and strongest part of the skull; and it is the most exposed, since it is the part of the head which would strike upon the ground when a man falls backwards."*

Of the Spine.—The spinal column, in man, is a vertical, elastic pillar, expanded inferiorly where it rests upon the sacrum. It is composed of a series of light, and spongy bones, between each pair of which (except the first) a compressible and elastic disc of fibro-cartilage is placed. It has a three-fold office in the human subject: first, it is the great bond of connexion between all the parts of the skeleton; secondly, it forms a canal for the lodgement and protection of the spinal cord; and, thirdly, it is a column of support for the head. For these purposes, the spinal column requires considerable strength, as the central pillar of the trunk: it needs mobility, to adapt itself to the various attitudes and movements of the body; and elasticity, to guard the tender organ contained within it, as well as the brain, from concussion.

The strength of the spinal column is abundantly provided for in the powerful ligament which binds the bodies of the vertebræ together in front (*anterior common ligament*), and in the strong and elastic intervertebral discs, which at once connect and separate them. The degree of motion which may take place between any two vertebræ is regulated partly by the thickness of the intervertebral disc, and partly by the disposition of the joints of the articular processes. When the latter are vertical in their direction, the vertebræ are so locked in, that their movements are very much impeded; but when they approach the horizontal direction, as in the neck, the range of motion is greater. The mobility of the spine may be compared to that of a chain; between any two links of which there is but little motion, while the whole chain is abundantly pliant. This restriction of motion between each pair of vertebræ enhances the strength of the column, and affords complete protection to the spinal cord, which would speedily suffer, did any vertebra pass beyond its prescribed limits.

In the flexuous form of the spinal column, and in the connexion of the vertebral laminæ by broad bands of yellow elastic ligament, we see further provision for its elasticity, in addition to that afforded by the discs of fibro-cartilage which lie between the bodies of the vertebræ. The concavity in the region of the back is doubtless intended to give full scope to the play of the important organs within the thorax; and the cervical and lumbar curves necessarily result from this, in order that the relation of the whole column to the line of gravitation of the body may be duly preserved. The

* Sir C. Bell.

triple curvature of the spine enables it to yield with less jerk than if it were a straight spring, or one that could bend only in a single direction. "It yields in the direction of its curves, and recoils, and so forms the most perfect spring, admirably calculated to carry the head without jar or injury of any kind."

The pliancy of the spinal column favours its flexion in various directions, in obedience to the action of the numerous muscles which are inserted into the vertebral processes. Nothing is more common than to see a misshapen and crooked spine produced by the predominance of action given to certain sets of muscles, through the habitual assumption of awkward attitudes: most of the curved spines which occur in weakly females may be traced to uncorrected bad habits as their origin.*

The spine, gradually expanding at its lower part, rests upon the base of the sacrum; and the last lumbar vertebra is separated from that bone by a fibro-cartilaginous disc. The sacrum forms a wedge separating the pelvic bones, and is admirably adapted to transmit the weight of the spine to them.

Of the Pelvis.—"The spinal column," to use the words of Mr. Mayo, "rests on an elastic hoop, in the extreme circumference of which on either side the deep cups are wrought which receive the heads of either thigh-bone. But this elastic hoop is not disposed vertically, but slants in such a manner, that, when we alight upon our feet, the force of the arrested motion tells in great measure on the extensor muscles of the hip."

In the articulation of the sacrum with the ossa innominata we see remarkable provision against its displacement backwards, by a force acting from above downward, the direction in which the superincumbent weight bears, or even by one acting from before backwards. This security is obtained not only by the strong ilio-sacral ligaments, which tie the bones together behind, and the cartilage, which intervenes between the ilium and sacrum, and adheres firmly to both, but also by the double wedge-like shape of the sacrum itself; for this bone is wider above than below, so that it can thereby resist the downward pressure; and it has a greater width before than behind, which enables it to oppose the pressure in front. And Mr. Ward has shewn that the sacrum is also well secured against displacement *forwards*, not only by the general compactness which the sacro-iliac joints derive from their ligaments and cartilages, but also by the cuneiform character which the bone

* Dr. Arnott's remarks bearing upon this subject deserve a careful perusal. —See his Elements of Physics, vol. i. p. 223, et seqq.

assumes about the middle of the articular surface, where the base of the wedge is turned in the opposite direction to that which it occupies either at the upper or the lower part of the articular surface.*

These provisions for the strength and security of the sacrum are of great importance to the general mechanism of the pelvis, whether we regard it as a bony girdle constructed for the transmission of the weight of the trunk to the thigh-bones, or as an osseous cavity destined to contain and protect certain important viscera.

Viewing the pelvis in the former light, we must notice the thickening of the iliac bones along either side of its upper outlet. The groinings, thus formed, terminate opposite the acetabula, and transmit the superincumbent weight, which they share with the sacrum, to each of those cavities, whence it is again transferred to the heads of the thigh-bones: they are formed of dense compact substance, which contrasts strikingly with the thin lamellated structure of the surrounding osseous tissue.

The obliquity of the pelvis has a two-fold object: first, with reference to the weight from above: and, secondly, with respect to concussions transmitted upwards by the lower limbs, in leaps, or other rapid movements. In both instances, the shock is distributed over a greater extent of surface, and is participated in by a greater number of joints, than if the pelvis were placed directly beneath the spine; for it is obvious, that, were the axis of the pelvis vertical, and the femora placed perpendicularly under it, the weight from above would bear its chief force upon the sacrum, and the concussion from below would be felt in the hip-joints alone.

In progression, the whole pelvis receives the concussions, when they proceed from above or from below. Hence the ossa pubis are united by an intervening elastic fibro-cartilage; and any disturbance of this joint during pregnancy, or in the act of parturition, occasions great difficulty to the patient in walking, or even in maintaining the erect posture.

Of the Thorax.— The thorax is a conoidal cavity, slightly flattened on its anterior aspect. It is constructed with obvious reference to lightness, elasticity, and mobility; all these qualities being requisite for its adaptation to the ever-varying movements of the organs it contains.

The walls of the chest are formed behind by the dorsal vertebræ, to which twelve ribs are articulated on each side; seven of these, the true ribs, are connected to either margin of the sternum by

* We refer for further details on this subject to Mr. Ward's excellent work, p. 256.

pieces of cartilage, which are of the same shape and breadth as the ribs themselves. The ribs are articulated by their heads and tubercles with the bodies, as well as with the transverse processes of the vertebræ, and enjoy at these points a limited gliding motion in the upward or downward direction. The direction of the true ribs is forwards, sloping downwards; the obliquity being greatest in the lowest ribs, least in the first rib. The mobility which each rib enjoys at its vertebral articulation, permits this direction to be altered by muscular action; and the ribs, under the influence of their elevator muscles, pass from the sloping to the horizontal position. By this change the dimensions of the chest are enlarged in the transverse as well as in the antero-posterior direction, for the middle curved portions of the ribs are carried outwards, and therefore brought further apart from each other; and their sternal extremities are moved forwards, accompanied by the sternum, the distance of which from the dorsal vertebræ is thereby increased. The forces, which depress the ribs, restore their planes of position to their previous oblique direction, and the two diameters of the chest to their former dimensions. It is scarcely needful to add, that the elevation of the ribs accompanies inspiration, and their depression expiration.

The following happy comparison between the thorax and the pelvis is from the pen of Mr. Mayo.

"When we compare together the several regions of the trunk, we observe that it is laid out in corresponding organs, or pairs of organs, on either side of a centre, which is formed by the five lumbar vertebræ. Above the lumbar vertebræ are the dorsal; above these, the cervical: below the lumbar vertebræ are the sacral bones; below these, the coccygeal. To the dorsal vertebræ and to the sacrum, bones are articulated, which have the double office of forming a visceral cavity, and of throwing to a convenient distance from the mesial plane the bones of the extremities. The ribs and sternum, the clavicles and scapulæ, form, with the dorsal vertebræ, an organ strictly analogous to that formed by the ossa innominata and the sacrum. But the chest for the function of respiration requires to be continually altering its dimensions, and the upper extremity is characterized by the extent and velocity of its movements, rather than by strength: to suit both these objects, the chest and shoulder are formed of many bones, that are moveable in various senses; the ribs are capable both of rotating upon their sternal and vertebral joints, and of being raised or depressed upon their vertebral joints, carrying with them the sternum; the clavicle again rolls upon the sternum, and the scapula rolls upon the convexity of the ribs. On the other hand, the pelvis, as regards the viscera, is intended merely for their support; and if, during labour, a temporary enlargement of its lower aperture is requisite, the flexibility of the joints of the os coccygis in the female skeleton, with the temporary yielding of the ligaments, affords a sufficient provision for this object; the inferior extremities again require to be articulated to a solid, unyielding platform, upon which they may poise the incumbent weight of the trunk and head. The bones of the pelvis are for these reasons few, weighty, massive, and knit together immovably. Thus accurately do the points, in which a resemblance is wanting between the chest and pelvis, preserve the analogy between these parts."

Of the Extremities.—In no part of the skeleton is the adaptation of anatomical disposition and structure to function more strikingly obvious than in the bones of the extremities.

The lower extremities form powerful pillars of support for the trunk in the erect posture. The great strength of the femur and tibia, which form the principal portion of each pillar, fit them admirably for this office; and it is interesting to notice that dense osseous tissue in each of these bones is most abundant in those situations where the greatest strain of the pressure from above is felt. This may be seen in a transverse section of either, when a dense spine of bone is found corresponding to the concave surface of each; this is most distinct in the femur, where the dense bone alluded to constitutes the *linea aspera*.

The femur is curved forward, and this incurvation gives elasticity to the bone, and aids in distributing the force of concussions. Its shaft is inclined downwards and inwards, so that the opposite femora approach each other inferiorly at the knee-joints, while they are separated by a considerable interval above. And this interval is increased by the head and neck of each femur being united to the shaft at an obtuse angle: this angle is one of about 135 degrees in the male; it is somewhat smaller in the female.

It is evident that the femur must suffer in point of strength from this mode of junction of its neck and shaft, for a bone without any bend in its axis must necessarily be more capable of resisting downward compression, than one consisting of two pieces united at an angle. But we observe here, as in other parts of the mechanism of the human body, that the disadvantage in one respect is more than counterbalanced by certain advantages which this peculiar arrangement offers, and which could be attained in no other way; for the junction of the neck with the shaft throws the thigh-bone outwards to a certain distance, and leaves abundant room for the play of the adductor muscles: this could only be attained otherwise by greatly enlarging the pelvis in the transverse direction. And again, in the movements of the femur, much is gained; for rotation can be performed with little muscular effort by reason of the favourable leverage afforded by the neck of the bone and the trochanter major. The increased power thus given to the rotator muscles has considerable effect in walking, which is on that account performed more lightly, and without any circumduction of the limb.

It is owing to this disposition of the neck of the thigh-bone, that, when its lower extremity advances in the vertical plane, its head and neck turn on a horizontal axis; in other words, that the *angular* motion of its shaft is converted into a *rotatory* movement at the hip-joint. And from such an arrangement this great advantage results, that in the various motions or states of the joints, as extreme or partial flexion, extension, &c., the same, or very nearly the same, extent of the articulating surfaces is exposed to pressure: for, as Mr. Ward expresses it, the rotation of a hemispherical head within a socket of the same form involves no diminution of the extent of the contiguous articulating surfaces; but the angular motion of a joint of this kind throws part of the ball out of the socket, and leaves part of the socket without bearings to rest upon, so that the weight, instead of being distributed equally over the whole surface of the head, is concentrated upon that portion which remains within the cavity.*

Moreover, the joint gains as regards the extent of flexion by this conversion of angular into rotatory motion, for an angular motion in the acetabulum would be readily checked by the edge of the cavity coming in contact with the neck of the bone; "whereas rotation meets no such check in the conformation of the joint itself, but may be continued indefinitely, until opposed by the tension of ligaments, or some other adventitious obstacle."

In the structure of the extremities of the femur, we find evidence of much beautiful mechanical contrivance, in the disposition of the compact tissue, and of the rods or fibres of the cancellous texture, having an obvious reference to the direction of the weight to be sustained as well as to the dispersion of concussions. The neck of the thigh-bone, having to bear considerable superincumbent weight, is strengthened on its inferior surface by an arch of compact tissue, gradually increasing in thickness as it proceeds from above down-

* Ward, loc. cit.

wards, and well suited by its rigidity to oppose bending; but on its upper surface the compact tissue is thin, and the reticular texture consists of somewhat arched fibres freely interwoven, running parallel to that surface, and disposed so as to present a surface to resist the direct influence of pressure (fig. 18, p. 102). The direction of the fibres of the reticular texture of the inferior part of the neck is chiefly downwards to the trochanter minor, and it seems to establish a communication between the osseous tissue of the head of the bone, and the dense structure which forms the lower part of the neck.

The lower extremity of the femur is almost entirely composed of cancellated texture, and affords a broad surface for articulation with the head of the tibia to form the knee-joint. As the tibia is placed vertically under it, it not only transfers the weight from above to that bone, but it is particularly exposed to suffer from concussions conveyed upwards by the tibia. Its structure seems disposed so as to facilitate the dispersion of such concussions, the sides of the condyles projecting considerably beyond the surface of the shaft of the bone, and there being but little continuity of tissue between it and the lower end of the bone.

Of the bones of the leg, the tibia, from its strength and size, is evidently that which is destined to support the thigh; the fibula must be regarded as entirely accessory in its office, affording attachment to the interosseous ligament, and forming a greater extent of surface for the origin of muscles. By its lower extremity it supports the ankle-joint on the outside.

The tibia rests upon the astragalus, and through that bone transmits the weight to the foot. The length of this organ, its breadth, and its arched form, adapt it as a basis of support for the body in the erect posture, and as an instrument of locomotion. It obtains elasticity, and a certain amount of mobility, from its being composed of several small and light bones articulated together. These bones, although almost entirely composed of reticular texture, possess considerable power of resistance to direct pressure in those directions in which the strain would chiefly bear in the movements of the organ, and this is to be attributed to the direction of the fibres of their cancellous tissue. The principal elasticity of the foot is longitudinal, by reason of its arch being in that direction, resting upon the heel behind, and on the toes in front; but it also yields somewhat in the transverse direction, or that of the arch formed by the cuneiform bones. The extension of the os calcis backwards not only adds to the length of the longitudinal arch, but it also affords a considerable leverage to the muscles of the calf of the leg.

Upper Extremity.—The disposition and structure of the bones of the upper extremity afford a marked contrast to those of the lower. The latter are organs of support, and therefore are solid, firm, strong, and, withal, elastic. The former are destined to perform extended motions, as well as minute and nicely adjusted ones; and, therefore, while they possess all the requisite strength, they are light, present little expanse of surface, and are articulated by numerous very movable articulations.

The scapula and clavicle are the media through which the bones of the arm are united to the trunk. The former bone is remarkably thin and light, and seems little more than a surface of attachment for various muscles, on whose actions the extensive movements of the arm depend. By the clavicle it is connected to the sternum, through the sterno-clavicular articulation, the movements of which, although occurring only in two planes, intersecting each other at right angles, are such as to favour a wide range of motion in the shoulder. So necessary is this joint to the general movements of the shoulder, that any injury or disease of it, or of the bone itself, shews itself speedily in the impediment offered to those movements. And the law of the development of this bone in the lower animals is clearly connected with a necessity for a wide range of motion in the anterior extremity. In those animals that employ the anterior extremity only as an instrument of progressive motion, there is no clavicle; hence this bone is absent from the skeletons of Pachydermata, Ruminantia, Solipeda, and the motions of the shoulder are only such as may be required for the flexion and extension of the limb. In the Carnivora, where there is a slight increase in the range of motion of the anterior extremities, a rudimentary clavicle exists; and in this class we observe that the size of the bone bears a direct relation to the extent of motion enjoyed by the limb. Thus it is smallest in the dogs, and largest in the cats: in these animals it has no attachment to either the sternum or the scapula, but is enclosed in the flesh, and does not occupy much more than half the space between the two bones last named. "But however imperfect," says Sir C. Bell, "it marks a correspondence in the bones of the shoulder to those of the arm and paw, and the extent of the motion enjoyed. When the bear stands up, we perceive, by his ungainly attitude, and the motion of his paws, that there must be a wide difference in the bones of his upper extremity from those of the ruminant or soliped: he can take the keeper's hat from his head, and hold it; he can hug an animal to death. The ant-bear, especially, as he is deficient in teeth, possesses extraordinary power of hugging with his great paws; and, although harmless in disposition, he can squeeze his enemy, the jaguar, to death. These actions, and the powers of climbing, result from the structure of the shoulder, or from possessing a collar-bone, however imperfect." *

In those Mammalia that dig and burrow in the ground, or whose anterior extremities are so modified as to aid them in flight, or which are skilful in seizing upon and holding objects with their paws, the clavicle is fully developed, and extends the whole way from the scapula to the sternum. Thus in the Rodentia this bone is very perfect, as, for example, the squirrel, the beaver, the rabbit, the rat, &c. The bat affords an example of a very strong and long clavicle, as also do the mole and the hedge-hog among the Insectivora.

Among the Edentata those tribes possess a clavicle whose habits are fossorial, as the ant-eater, the armadillo, and even the gigantic extinct megatherium. In the Quadrumana the clavicles are strong and curved, as in the human subject.

The clavicle possesses considerable elasticity by reason of its curves; a property obviously of the greatest importance to it, because, as the bond of connexion of the shoulder to the trunk, it is liable to participate in the many concussions to which the upper extremity is exposed. This point has been put to the test of direct experiment by Mr. Ward. He employed the clavicle of a well-developed male subject, of the middle age: this was placed upon a smooth surface, with its shaft perpendicular to the plane of a wall, against which its inner extremity rested; a smart blow was then struck with a hammer on the outer extremity of the bone, in the direction of its long axis; the hammer rebounded from the end of the bone, which sprang to a distance of nearly two feet from the wall.

The humerus is the principal lever of the upper extremity: in man it is light, and its articular extremities are constructed to contribute to the formation of very moveable joints. The bones of the fore-arm are also remarkable for their lightness and elasticity; and they move freely, not only on the humerus, but on each other. The movements of pronation and supination, which are necessary to the free and full use of the hand, are performed by the rotation of the radius round an axis passing through its head and neck; the slight curve in the shaft of the radius causes its carpal extremity to

* Bridgewater Treatise, p. 49.

pass through a considerable space during the rotation of the fore-arm.

The contrast between the solidity and elastic firmness of the foot and the lightness, flexibility, and mobility of the hand, is most striking. The analogy between the anatomical elements of both organs is complete: but they are modified to suit the office for which each is destined; the foot as a basis of support, the hand as a prehensible organ. The hand is modified remarkably from the form of the foot by the divergence of the outer metacarpal bone, to form the thumb: this bone, at its articulation with the carpus, enjoys a considerable degree of mobility, in virtue of which exists the opposable faculty of the thumb; a power which, in a state of perfection, is peculiar to the human hand.

While the hand is so remarkably mobile, it is well protected against the effects of compression, or concussion, by the number of its joints, and the interposed cartilages and fibro-cartilages, and the soft covering of fat which lies beneath the skin of the palm; and its strength is abundantly provided for in the strong ligaments which connect the bones to each other, and the fibrous expansions which cover them.

One of the most wonderful circumstances in the construction of the hand, is its adaptability to an infinite number of offices. A powerful organ of prehension, it is yet capable of adjusting the finest pieces of mechanism, or of exposing to view the minutest wonders of nature: an admirable and most delicate instrument of touch, it may nevertheless be employed as a fearful and deadly weapon of offence: at one time it may be used to lift great weights, to pull at the cable, or to turn the windlass; and, again, it will execute the most varied and rapid movements, in the performance of works or artifices which human talent has invented.

The hand is the obedient minister of man's volition and of his genius, and, too often, the blind slave of his emotions and his passions.

The following references are subjoined:—The various treatises on General Anatomy; the article Articulation, in the Cyclopædia of Anatomy and Physiology; Mayo's Physiology, chap. xi.; Bell's Animal Mechanics; Arnott's Elements of Physics, vol. i. p. 218; Anatomie Descriptive, par Bichat, t i.; Outlines of Human Osteology, by F. O. Ward, a work to be strongly recommended, as well for its exact and clear descriptions, as for the excellent and original views on the mechanism of the skeleton, with which it abounds. We shall be glad to see it published in a form more suitable to its great merit.

CHAPTER VII.

ACTIVE ORGANS OF LOCOMOTION.—OF MUSCLE.—MUSCLE WITH STRIPED FIBRES.—MUSCLE WITH UNSTRIPED FIBRES.—MUSCULAR ACTION.—ATTITUDES AND MOVEMENTS OF THE FRAME.

THE principal movements of the body, and all those by which locomotion is effected, are performed by means of a tissue termed *muscle*, endowed with the power of contracting, and consisting chemically of fibrine. This substance is arranged in the form of unbranched fibres of definite size and structure, and which, when examined under a high magnifying power, are found to be of two kinds, distinguishable from one another by the presence or absence of very close and minute tranverse bars or stripes. The fibres of the *voluntary* muscles (or those whose movements can be either excited or controuled by volition), as well as the fibres of the heart, and some of those of the œsophagus, are *striped;* while all other muscles, including those of the alimentary canal, the uterus, and bladder, all of which are *involuntary*, are *unstriped.*

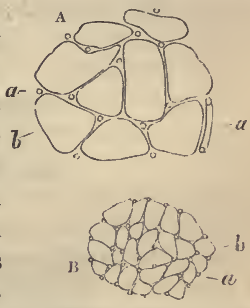
The elementary fibres of the voluntary muscles are connected to one another by areolar tissue, and arranged in sets parallel to one another. They are supplied with vessels and nerves, which lie in the intervals between them; and are attached, by their extremities, through the medium of tendon, aponeurosis, or some form of the fibrous tissue, to the parts which they are destined to move. They form organs, for the most part solid and elongated, but which are sometimes expanded into a membranous shape.

The sets of fibres of the involuntary muscles, on the other hand, usually cross each other at various angles, and interlace, and they are always arranged as membranous organs enclosing a cavity, which their contraction serves to constrict. The heart, besides being independent of the will, agrees in both these anatomical characters with the involuntary muscles, and is only allied to the voluntary by the presence in its fibres of the transverse stripes.

We shall commence with a description of the two forms of fibre.

Of the Striped Fibres.—The length of these is usually about that of the muscle to which they belong, but occasionally they are interrupted by tendinous intersections, as in the rectus abdominis and semitendinosus; and it is very common for them to fall short of the length of the whole organ, in consequence of an oblique disposition, as seen in penniform muscles. In the sartorius they often exceed two feet in length, while in the stapedius they are not two lines. They vary in diameter from $\frac{1}{60}$ to $\frac{1}{1500}$ of an inch, being largest in crustacea, fish, and reptiles, where their irritability is enduring; and smallest in birds, where it is most evanescent. The individual fibres, however, vary considerably in thickness in the members of the several tribes, and even in the same animal and muscle. Their average width in man is about $\frac{1}{400}$ of an inch. They are not cylindrical, but flattened more or less, by being closely packed together. This may be ascertained in the recent state, or still better by a transverse section of a dried muscle. Small interspaces are left, however, for the passage of the capillary blood-vessels along the angles of junction, and sometimes between the contiguous sides. (Fig. 36.)

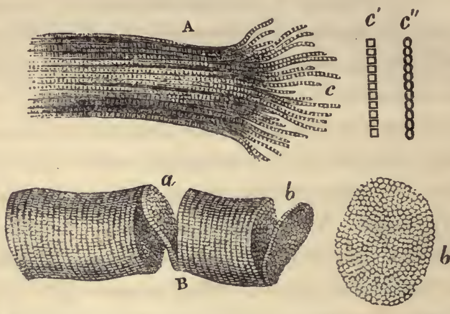
Fig. 36.



Transverse sections of striped muscle that had been injected and dried, magnified 70 diameters:—A. From the Frog. B. From the Dog. *b, b.* Section of elementary fibres, shewing their angular form and various size. *a, a.* Sections of the injected capillaries, shewing the position they occupy among the fibres. *a'.* Transverse branch between two longitudinal capillaries. These figures shew the greater vascularity of the muscle, with the narrower elementary fibres.

Internal Structure.—The beautiful cross-markings on the voluntary fibre have been known from the early days of microscopical research, and have given occasion to a variety of hypothetical and generally mechanical solutions of the problem of contraction; which, by warping the minds of observers, have had the effect of greatly complicating an already difficult subject, that of the internal anatomy of the fibre, which can only be determined by pure observation. Fontana alone among the older anatomists abstained from vague speculation; and he arrived nearest to the truth. He found that the fibre was apt to split up into fine fibrillæ, each of which was a series of particles; and he imagined that the transverse lines were caused by the regular apposition side by side of the particles of the contiguous fibrillæ. It was customary both before and since his time, as at the present day, to regard the fibre as a bundle of smaller ones, whence the term *primitive fasciculus,* first given to it by him and adopted by Müller: but this view of the subject is imperfect. The fibre always presents, upon and within it, longitudinal dark lines, along which it will generally split up into fibrillæ; but it is by a fracture alone that such fibrillæ are obtained. They do not exist as such in the fibre. And, further, it occasionally happens that no disposition whatever is shewn to this longitudinal cleavage; but that, on the contrary, violence causes a separation along the transverse dark lines, which always intersect the fibre in a plane perpendicular to its axis. By such a cleavage, discs, and not fibrillæ, are obtained; and this cleavage is just as natural, though

Fig. 37.



Fragments of striped elementary fibres, shewing a cleavage in opposite directions; magnified 300 diameters; — A. Longitudinal cleavage. The longitudinal and transverse lines are both seen. Some longitudinal lines are darker and wider than the rest, and are not continuous from end to end; this results from partial separation of the fibrillæ. *c*. Fibrillæ, separated from one another by violence at the broken end of the fibre, and marked by transverse lines equal in width to those on the fibre. *c′*, *c″*. represent two appearances commonly presented by the separated single fibrillæ. (More highly magnified.) At *c′*. the borders and transverse lines are all perfectly rectilinear, and the included spaces perfectly rectangular. At *c″*. the borders are scalloped, the spaces bead-like. When most distinct and definite, the fibrilla presents the former of these appearances. — B. Transverse cleavage. The longitudinal lines are scarcely visible. *a*. Incomplete fracture following the opposite surfaces of a disc, which stretches across the interval and retains the two surfaces in connexion. The edge and surface of this disc are seen to be minutely granular, the granules corresponding in size to the thickness of the disc, and to the distance between the faint longitudinal lines. *b*. Another disc nearly detached. *b′*. Detached disc more highly magnified, shewing the sarcous elements.

less frequent than the former. Hence it is as proper to say that the fibre is a pile of discs, as that it is a bundle of fibrillæ; but, in fact, it is neither the one nor the other, but a mass in whose structure there is an intimation of the existence of both, and a tendency to cleave in the two directions. If there were a general disintegration along all the lines in both directions, there would result a series of particles, which may be termed *primitive particles* or *sarcous elements*, the union of which constitutes the mass of the fibre. These elementary particles are arranged and united together in the two directions. All the resulting discs as well as fibrillæ are equal to one another in size, and contain an equal number of particles. The same particles compose both. To detach an entire fibrilla is to abstract a particle of every disc, and *vice versâ*. The width of the fibre is therefore uniform, and is equal to the diameter of any one of the discs. Its length is the length of any one of its fibrillæ, and is liable to the greatest variety.

Müller, Schwann, Lauth, and others, consider, with us, that the cross stripes of the fibre are formed by the apposition side by side of the dark points seen on the separated fibrillæ; but some believe these stripes to be present only on the surface of the fibre, and to be formed by the spiral windings of a filament. Considerable diversity of opinion also exists as to the nature of the alternate light and dark points seen on the individual fibrillæ; some conceiving them to indicate a single spiral, others a double spiral arrangement; some imagining them to be minute zigzag bendings, others indentations, and others still that they depend on the alternation of two kinds of substance. On this account we shall explain in a few words our reasons for adopting the view above summarily given. A soft mass made up of an immense congeries of highly refracting particles cannot but exhibit many deceptive appearances when viewed by transmitted light, and through glasses of bad defining power. The slightest disturbance of its interior structure will affect the refractions, which will thus be readily made to disguise and modify the true form and arrangement of its integrant parts; on which account great care and circumspection, and a total freedom from bias, are requisite for an observer who would not be misled to mistake appearances for realities.

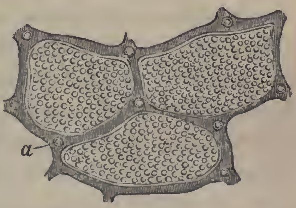
That the stripes are not caused by a structure distinct from the fibrillæ, and present only on the surface of the fibre, is evident from the following facts:

1. That a transverse section of a fibre shews it to be solid, and not hollow; and that the ends of fibrillæ, as seen on the section, exist throughout its interior just as on its surface (fig. 38).

2. That fibrillæ taken from any part of a fibre are marked with light and dark points, corresponding in distance and force with the transverse stripes of the fibre.

3. That with a high magnifying power, applied to a thick fibre, we may bring all parts of its interior into focus in succession, and perceive throughout the same kind of stripes.

Fig. 38.



Transverse section of three elementary fibres of the dried pectoral muscle of the Teal (*Querquedula crecca*), treated with weak citric acid; showing the round refracting particles separated from one another. The cut edge of the tubular sheath of each fibre is also seen, as well as the capillary vessels, *a*, in the intervals.

The occasional *appearance*, therefore, of these stripes being confined to the surface is deceptive. They are sometimes more strongly marked there, partly because there is a greater condensation of the tissue there, and partly from the circumstance of the fibre being usually immersed, when examined, in a fluid of less density than itself. This appearance is always greatly diminished by placing the fibre in syrup. But the point of greatest interest is as to the nature of the markings on the individual fibrillæ or discs. It is unsafe to come to a conclusion on this question from any appearances seen on the entire fibre; for it is clear that the relative position of the particles may be very easily deranged, and their regularity broken, by the slightest injury to the mass.

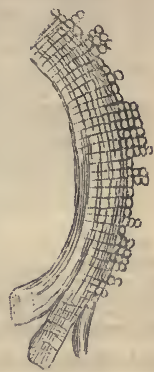
Two *appearances* commonly present themselves in examining the striped fibres: in some parts the cross stripes are perfectly rectilinear, or, if curvilinear, parallel in their course; in other parts, these stripes do not extend across the fibre, but are more or less interrupted, forming zigzags and enclosing spaces of a great variety of shape and size, in concert with the longitudinal stripes. In such specimens we see the semblance of spirals in almost infinite number and variety. The former of these appearances is most seen in large fibres, and where great care has been used not to drag the tissue; the latter under the reverse circumstances. The former seems on a *prima facie* view un unmutilated, the latter a deranged condition; and they may be proved to be so by a further examination.

For this purpose we should make choice of a fresh fibre which is prone to separate into its individual fibrillæ, and which exhibits their outline in the greatest distinctness and beauty.* If fibrillæ entirely isolated be now inspected, they will be found to present alternate light and dark points, when the part is a little out of focus. The light parts are the centres of highly refracting particles, acting as lenses; the dark points, the intervals between them (fig. 37, *c''*). If now the focus be carefully adjusted, and the achromatic condenser be employed for the purpose of defining the outline with the utmost precision, each dark interspace between the refracting points will be found to be reduced to two very slender straight lines, crossing the fibrilla in a perfectly *transverse* direction, and giving the light spaces, as now seen, a *rectangular* figure (fig. 37, *c'*). Now, it is absolutely certain that no spiral arrangement could produce, or even co-exist with, these unequivocal appearances; but it is not difficult to comprehend how a derangement of the lateral parallelism of these refracting particles should produce an appearance of spirals in the fibre, or how two fibrillæ running together, but with their particles slightly deranged, should wear the same very deceptive aspect.

* The fibres of fishes will generally prove better than those of mammalia, because they usually cleave into fibrillæ having very sharp and clear outlines; and those of the salmon, for example, will seldom fail to do so.

In fig. 39 is represented the border of some fibres, from which several of the sarcous elements have been removed accidentally by maceration in weak spirit. The remaining ones project in lateral series, evincing their adhesion to one another in that direction, and the non-existence of any spiral arrangement.

Fig. 39.



The size of the particles composing the fibre may be measured in one direction by the transverse stripes formed by their union.

The following average, deduced from numerous observations, shews great uniformity in this respect.

	Eng. In.	No. of Observations.
In the Human subject	$\frac{1}{9400}$	27
„ Mammalia generally	$\frac{1}{10900}$	15
„ Birds	$\frac{1}{10400}$	7
„ Reptiles	$\frac{1}{11500}$	7
„ Fish	$\frac{1}{11100}$	20
„ Insects	$\frac{1}{9500}$	8

In the opposite direction, or that marked by the distance between the longitudinal dark lines of the fibre, their diameter is less, often by one half. It is important to remark, that these measurements are taken from uncontracted specimens, since during contraction the relative diameters of the particles are changed.

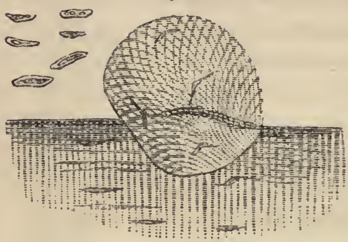
Of the Sarcolemma.—The striped fibre is enclosed in a tubular sheath or *sarcolemma*, adapted to its surface, and adhering to it. This consists of a transparent, very delicate, but tough and elastic membrane, which isolates the fibre from all other tissues. In general, it has no appearance of any kind of structure; but in the case of bulky fibres, where it is strong in proportion, faint indications may be detected of a complex interweaving of filaments far too minute to be individually recognised. It occasionally has small corpuscles, the remains of cell-nuclei, in contact with it.

Fig. 40.

Fragments of an elementary fibre of the Skate held together by the untorn but twisted sarcolemma.

This membrane may be sometimes seen forming a transparent border to the fibre beyond the

Fig. 41.

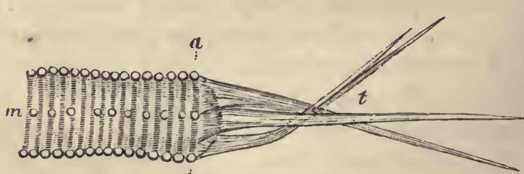


Part of an elementary fibre from the Skate, treated with liq. potassæ; shewing a protrusion through the sarcolemma: – Corpuscles are seen scattered throughout the mass, and some detached ones are represented; their average diameter is one thousandth of an English inch.

limit of the cross-stripes; or it may be seen stretching between the separated fragments of a fibre which has been broken within it, for its toughness will often resist a force before which its brittle contents give way. If the fibre be immersed in acid, it swells, often so suddenly as to burst the sheath at numerous places, and protrude in the form of small herniæ. These herniæ are very peculiar, and illustrate the account already given of the internal composition of the fibre; for the particles of the protruded mass are necessarily deranged, and their lateral parallelism destroyed. Now, the result of this is the production of the most beautiful and varied curves, intersecting one another, very similar to those already spoken of on the injured fibre, and wearing a very plausible aspect of spirals (fig. 41). Again, the sarcolemma may be seen raised in the form of vesicles from the surface of the fibre, in certain states of contraction in water, which will be reverted to. By one or more of these modes of demonstration, we know that this isolator of the sarcous tissue invests the striped elementary fibre of voluntary muscle in all animals. Its existence is as yet doubtful in the heart.

Every fibre is attached by its extremities to fibrous tissue, or to some tissue analogous to it; but an accurate examination of this difficult subject lends no countenance to the ordinarily received opinion, that this tissue is prolonged over the whole fibre from end

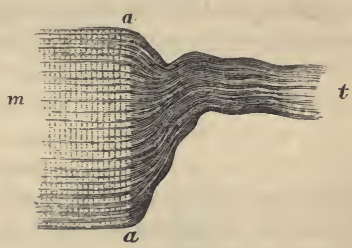
Fig. 42.



Elementary fibre from the leg of the large Meat-fly (*Musca vomitoria*):—*a. a.* Line of termination of the fibre, along which the tendon, *t*, is attached to it. *m.* Central series of corpuscles.—Along the margin, the sarcolemma is elevated by water (which has been absorbed), and is thereby shewn to be adherent to the margin of the discs.

to end, as its cellular sheath; nor is this view reconcilable with the physical requirements of the case. It is extremely difficult to isolate a muscular fibre, with the tendinous fibrillæ pertaining to it, either in mammalia or birds; but this may be occasionally accomplished in fishes, and in certain muscles of insects. In these examples, the minute detachment of the fibrous tissue may be seen to pass, and to become attached to the truncated extremity of the fibre. The fibre ends by a perfect disc, and with the whole surface of this disc the tendon is connected and continuous. The sarcolemma ceases abruptly at the circumference of the terminal disc, and here some small part of the tendinous material appears to be joined to it. In other cases, where the muscle is fixed obliquely to a membranous surface, each fibre is obliquely truncated at its extremity, at an angle determined by the inclination of its axis; instances of which may be seen among the crustacea, and elsewhere.

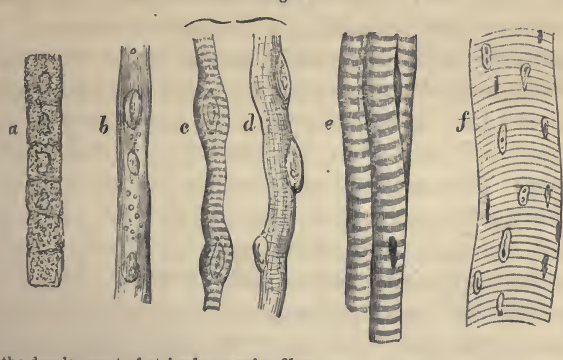
Fig. 43.



Attachment of tendon to an elementary fibre from the Skate:—On bringing deeper and deeper portions of the specimen into focus, along the line of union, *a. a.*, fresh tendinous wavy filaments and striated muscular parts came into view together. *t.* Tendon. *m.* Muscle.

The researches of Valentin and Schwann have shewn that a muscle consists, in the earliest stage, of a mass of nucleated cells, which first arrange themselves in a linear series, with more or less regularity, and then unite to constitute the elementary fibres. As this process of the union of the cells is going forward, a deposit of

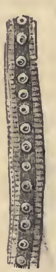
Fig. 44.



Stages of the development of striped muscular fibre.
a. Arrangement of the primitive cells in a linear series.—After Schwann.
b. The cells united. The nuclei separated, and some broken up; longitudinal lines becoming apparent.—From a fœtal calf three inches long.
c. d. Transverse stripes apparent. In *c*, the nuclei are internal, and bulge the fibre. In *d*, they are prominent on the surface.—From a fœtal calf of two months old.
e. Transverse stripes, fully formed and dark; nuclei disappearing from view.—From the human infant at birth.
f. Elementary fibre from the adult, treated with acid; shewing the nuclei.—Magnified about 300 diameters.

contractile material gradually takes place with them, commencing on the inner surface, and advancing towards the centre, till the whole is solidified. The deposition occurs in granules, which, as they come into view, are seen to be disposed in the utmost order, according to the two directions already specified. These granules, or sarcous elements, being of the same size as in the perfect muscle, the transverse stripes resulting from their apposition are of the same width as in the adult; but, as they are very few in number, the fibres which they compose are of corresponding tenuity. From the very first moment of their formation, these granules are parts of a mass, and not independent of one another; for, as soon as solid matter is deposited in the cells, faint indications of a regular arrangement in granules are usually to be met with. It is common for the longitudinal lines to become well-defined before the transverse ones. When both are become strongly marked, as is always the case at birth, the nuclei of the cells, which were before visible, disappear from view, being shrouded by the dark shadows caused by the multitudinous refractions of the light transmitted through the mass of granules: but they can still be shewn to exist in the perfect fibre, in all animals, and at all periods of life, by immersion in a weak acid; which, while it swells the fibrous materials of the granules, and obliterates their intervening lines, has no action on the nuclei.

Fig. 45.



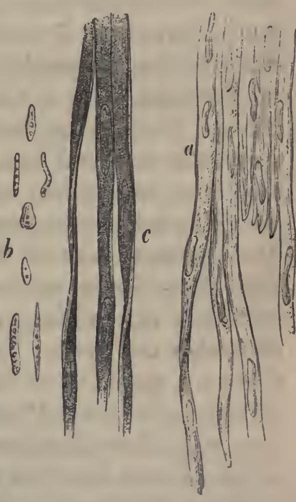
Elementary fibre from the larva of the Libellula, in an early stage of development; shewing the central row of corpuscles.—Magnified 300 diam.

These nuclei in insects are arranged, in the early condition of the fibre, as a single or double series along the axis (fig. 45); and, in the adult state, they retain the same position (fig. 42). In vertebrate animals they are scattered more irregularly, but at pretty equal distances throughout the mass in both fœtal and adult conditions. In the fully formed fibre, if it be large, they lie at various depths within it; but, if small, they are at or near the surface. They are oval and flat, and of so little substance, that though many times larger than the sarcous elements, and lying amongst them, they do interfere with their mutual apposition and union. These corpuscles are frequently the cause of irregular longitudinal dark streaks, seen in the fibre by transmitted light. They usually contain some central granules or nucleoli. It is doubtful whether the identical corpuscles, originally present, remain through life, or whether successive crops advance and decay during the progress of growth and nutrition: but it is certain that, as development proceeds, fresh corpuscles are deposited, since their absolute number is far greater in the adult than in the fœtus, while their number relatively to the bulk of the fibre, at these two epochs, remains nearly the same.

Muscles grow by an increase, not of the number, but of the bulk of their elementary fibres: there is reason to believe that the number of fibres remains through life as it was in the fœtus, and that the spare or muscular build of the individual is determined by the mould in which his body was originally cast.

Of the Unstriped Fibres.—This variety possesses less interest than the other, in consequence of the apparent simplicity of its structure. The fibres consist of flattened bands, generally of a pale colour, bulged at frequent intervals by elongated corpuscles, similar to those of striped muscle, and capable of being displayed by the same process.* The texture of these fibres seems to be homogeneous. By transmitted light, they have usually a soft, very finely mottled aspect, and without a darkly-shaded border. Sometimes the mottling is so decided as to appear granular, and occasionally these granules are arranged in a linear series for some distance. This condition is probably an approach towards the structure of the striped fibre, for these granules are about the size of the sarcous elements already described. It is generally to be seen more or less distinctly in the gizzards of birds; and may be now and then met with in the fresh muscle of the stomach, intestinal canal, urinary bladder, and uterus of mammalia. The ordinary diameter of the unstriped fibre is from $\frac{1}{3000}$ to $\frac{1}{2000}$ of an inch.

Fig. 46.



Fibres of unstriped muscle:—*c.* In their natural size. *a.* Treated with acetic acid, showing the corpuscles. *b.* Corpuscles, or nuclei, detached, shewing their various appearances.

It might be expected, from this account of the appearance of these fibres, that their discrimination from other tissues would be often difficult. The peculiar texture, however, the size, the soft margin, and, above all, the presence of numerous elongated oval corpuscles with two or three granules near their centre, are characters which, when united, will seldom be mistaken. As a number of fibres

* In some specimens, however, of both varieties of fibre, they may be discerned without the addition of an acid.

commonly take a parallel course together, the bulgings occasioned by the corpuscles give rise to partial longitudinal shadows, extending for some way beyond the corpuscles in the intervals of the fibres. As these irregular longitudinal shadows occur pretty uniformly throughout a bundle of fibres, and as some of them are necessarily out of focus, while others are in focus, the whole mass commonly presents a confused reticulated appearance, which has given rise to an almost universal notion, that the fibres interlace one with another. This idea, however, is, in most cases, erroneous. It is doubtful whether these fibres are invested by a sarcolemma: none has hitherto been detected in an unequivocal manner. It is also still a matter of speculation how they terminate, or whether they in all instances have a termination. In the case of the transverse fibres of the intestine, for example, it is uncertain whether each fibre surrounds the canal once, returning unto itself as a ring, or more than once, as a spiral; or whether it passes only partially round it, the circle being completed by others. Whether the areolar tissue (the representative of the fibrous), that is found in connection with these fibres, serves to give them an attachment, by union with their extremities, or by involving them in its meshes, is also altogether unknown. In the gizzard of the bird, the ends of the fibres are united to white fibrous tissue, thus making an approximation to the striped fibre, as they do in colour. But we have not been able, after diligent search, to detect the true transverse stripes, which Ficinus describes to exist in this organ.

Of the Distribution of the two Varieties of Fibre in the Body.—The striped fibre is met with in all muscles of the body whose action can be directly influenced by the will, and also in those of the pharynx, the œsophagus, and the heart. In the œsophagus it seems to be mingled with the other variety to a somewhat uncertain extent. In some specimens from the human subject we have failed in detecting any in the lower half of that tube, either in the circular or longitudinal layer; but in other examples we have found them to within an inch of the stomach.* It is still unknown in what manner the two kinds of fibre are arranged at their point of junction: some supposing them to be intermingled; others, that they pass into one another by imperceptible gradations of structure. The former of these views is the more accordant with our own observations; and Mr. Mayo mentions a fact, which seems to

* Among the lower animals, Mr. Gulliver has pointed out similar varieties. (Proceed. of Zool. Soc., No. 81.) (See also Lancet, Aug., 1842.)

corroborate it: "When the nervi vagi are pinched, one sudden action of the fibres of the œsophagus ensues, and, presently after, a second, of a slower character, may be observed to take place."* The characters of these movements would appear to indicate the existence of both varieties of fibre.

The cross stripes on the fibres of the heart are not usually so regular, or distinct, as in those of the voluntary muscles. They are often interrupted, or even not visible at all. In some of the lower animals their sarcous elements never form transverse stripes. These fibres are usually smaller than the average diameter of those of the voluntary muscles of the same subject by two-thirds, as stated by Mr. Skey; and in most parts of the parieties of this viscus they are not aggregated in parallel sets, but twine and change their relative position. This may be seen in a well-boiled heart. Striped fibres have been found in the iris, in the small muscles of the ear, and in those muscular fasciculi that surround the urethra immediately in front of the prostate. They are also found in the sphincters of the anus and vagina.

The unstriped fibre is met with in the alimentary canal, and constitutes the double layer investing that tube. It also forms the muscular coat of the bladder, and that of the uterus. The dartos owes its contractility to the presence of fibres of this variety; which, in consequence of their admixture with a great abundance of areolar tissue, have been often overlooked. But they may be detected by the addition of acetic acid, which, by bringing into view the peculiar corpuscles they contain, distinguishes them from both the white and yellow fibrous elements of the areolar tissue. A very distinct peristaltic contraction may be often discerned in the dartos, extending across the raphé of the scrotum, and too similar to the contraction of unstriped muscles to be mistaken.

The fibres which have been described as peculiar to the dartos seem to be nothing more than a certain modification of the areolar tissue in that region. The erection of the penis may be, in part, owing to the compression exerted on the superficial veins of the organ by a continuation of a structure analogous to the dartos, which is continued over the base of the penis under the skin. The erection of the nipple also occurs, on any mechanical irritation, with a motion so very like muscular contraction, that a layer of these might perhaps be found under the skin of that region. And it may be matter of question how far the general contractility of

* Physiology, 3d ed. p. 41.

the skin may be dependent on a diffusion of this tissue, in small quantities, throughout its areolar structure. The excretory ducts of all the larger glands seem to possess a covering of fibres pertaining to this variety: such is the case with the ductus choledochus in birds, and probably in mammalia, and with the ureters and vasa deferentia. The bronchial tubes may be here alluded to in their capacity of an excretory apparatus, as furnishing the best marked example of this arrangement. The trachealis muscle consists evidently of the unstriped fibres, and the same may be traced down the bronchial ramifications as far as the air-cells themselves, though not into them. The distinctive characters of this form of muscle may here be unequivocally discerned: and, if anatomists had been better acquainted with them, there would not have been room for those disputes regarding the muscularity of the bronchial tubes which have so long attracted the interest of practical physicians. Recently, indeed, there has been added to the satisfactory evidence of anatomy the fact, that these fibres may be excited to contraction by the galvanic stimulus.* In the case of other glands, it is still unknown how far the muscular coat invests the ramifications of the duct: it is most likely that it gradually ceases a short way within the organ, and at least it seems clear that no portion of the secreting membrane itself is ever invested by it.

Distribution of the two kinds of fibre in the animal scale.

The striped fibres have been found in all vertebrated animals, and in insects, crustacea, cirropods, and arachnida; and future researches will probably shew them to be even more extensively diffused. But, in the lower animals, we find that the distinctive characters of the two varieties begin to merge together and be lost; especially where the fibres are of diminutive size. The transverse stripes grow irregular, not parallel, interrupted; a fibre will, perhaps, possess them only near its centre, where its development is most advanced, and its contractile energy greatest. Even the peculiarities of the unstriped fibre are sometimes no longer to be met with in parts which are undoubtedly muscular, as the alimentary canal of small insects. It is evident that fibres of the usual bulk would be greatly too large for the requirements of the case; and they consequently seemed to be reduced within limits which deprive them of those anatomical characters by which alone we can elsewhere positively aver their existence. It is possible that a tissue identical in nature and properties with that of striped muscle, may be the effective agent to which are due those wonderfully vivacious movements witnessed in the bodies of many of the minutest infusoria, where the best microscope can hardly discern even the organs put in motion.

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* Dr. C. J. Williams, on Diseases of the Chest. Last edit. Appendix.

Each one of the elementary fibres now described may be properly regarded as a distinct and perfect organ. In some of the smaller forms of animal life, we have examples of a striped muscle consisting of a *single fibre;* and not only so, but this fibre reduced to a single series of sarcous elements, or a *fibrilla.* But in all the larger animals, and in the human body, with which we are specially concerned, solitary fibres never occur: they are always aggregated in parallel series of greater or smaller size, and associated with other tissues, which minister to their nutrition, or to their mechanical connexion either to one another or to neighbouring parts. Thus the compound organs termed *muscles* are formed.

In these, the angular figure of the fibres results from their contact. The sets in which they are packed usually contain ten, twenty, thirty, or more; these again being united into larger sets, and so on, so as to form the variously sized *fasciculi* and *lacerti* of Prochaska and others, until the whole muscle is formed, consisting, it may be, of very many thousands. Though the fibres of a small set are always parallel, and the primary sets usually so, it often happens that the larger sets are placed obliquely to one another, and therefore do not act in the same direction; and, even when all are parallel to one another, they are often oblique to the cord or tendon their force acts upon. Such muscles are styled doubly or singly *penniform,* from their resemblance to the plume on a writing-quill. All such arrangements, infinitely varied, are mechanical contrivances by which symmetry of form, or extent of motion, is obtained at the expense of power.

White fibrous tissue reaching from the end of a muscular fibre to some structure which is to serve as a fixed attachment for it, or which it is intended to move, is called a *tendon.* The fibrous tissue thus running from many contiguous fibres (as those of a whole muscle) is usually united into a single tendon. This may be lamellated, cordiform, &c., according to the arrangement of the muscular fibres themselves (see p. 71).

Tendinous fibres are much less bulky than the muscular fibres of which they are the prolongation; and from this result many consequences. Tendons are employed for symmetry, and where muscular structure would be useless, from the mechanical impossibility of more than a certain amount of motion in a part. Moreover, where a muscle consisting of a large number of fibres has to be attached to a large surface, the tendinous fibres are diffused; but, if the same muscular substance has to be fixed to a small point of bone, the tendon must be collected into a cord. Now, it would be impossible for all these muscular fibres to be attached to the tendinous ones on the same level, on account of the great difference in bulk between the two structures. Hence, in such cases, we find the muscular fibres to end in tendon in regular progression one after the other, and the tendon at its muscular extremity to be expanded, some of its fibres being long, others short. And yet the inconvenience which would ensue from the muscular fibres being of unequal length in the same organ is counteracted by the tendon at their other extremity having its fibres precisely reversed; as in the rectus of the thigh, and numerous other instances. Where muscular fibres are really of different lengths in a muscle, it is because, from the direction in which they act, they have to shorten to different degrees. Thus, in the square pronator of the fore-arm, the deeper and shorter fibres are attached to a part of the radius, which in pronation passes through a much smaller space than that to which the superficial and longer fibres are fixed: and under the innumerable modifications of muscular form in man and animals, however force is sacrificed to mechanical exigencies, or other causes, it is invariably accomplished with the utmost œconomy of power consistently with the end in view; there is never any waste, never any force provided which is not wanted.

Where a great mass of fibrous tissue runs into a muscle, the number and obliquity of the muscular fibres are very much increased, while the length of each is diminished; and, as a general result, the power of such a muscle is great, the extent of its contractions comparatively limited.

A given mass of contractile material may be arranged as a few long fibres (as in the sartorius), or as many short ones (as in the masseter): its contractions would, in the former case, be characterized by their extent; in the latter, by their power; for, *cæteris paribus,* the extent is as the length, the power as the thickness.

The terms *origin* and *insertion* are employed with great convenience in ordinary language, to denote the more fixed and the more moveable attachments of muscles. In human anatomy general consent has sanctioned their use, and even with few exceptions their particular application to each muscle in the body; although this assignment is in many cases arbitrary, in consequence of its being impossible to determine which attachment is the more frequently the fixed one.

The arrangement of the fibres in the *heart* is very peculiar. Without attempting a particular account of their course, we may state that they do not preserve the same parallelism, nor extend straight between two points, as in the voluntary muscles, but twine round one another, and around the organ, in a very intricate and more or less spiral figure. Most of them come from the tendinous cord encircling the orifices of the ventricles, and, after winding through their walls, return either to some part of the same circle of tendon, or end as one sort of columnæ carneæ in the ventricles by union with the chordæ tendineæ.

In the muscular coat of the alimentary canal, of the bladder and uterus, the unstriped fibres are disposed, as in the heart, so as to enclose a cavity, but without having, as in that organ, any point at which they can be said to commence or terminate. In the alimentary tube they are arranged in two laminæ, the respective fibres of which take a course at right angles to each other. In the bladder the arrangement is reticulate. The elementary fibres form sets of variable thickness, which at numerous points send off detachments to join neighbouring bundles, whence has sprung the notion that the fibres are branched. It is manifestly, however, the sets of them only that are branched; the unstriped, like the striped fibres, being invariably simple from end to end. In the uterus the disposition of the fibres is essentially similar, calculated to allow of great variety in the capacity of the cavity they encircle.

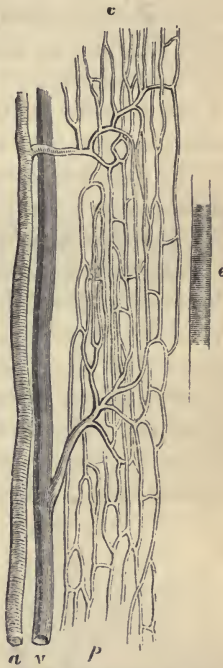
Of the Areolar Tissue of Muscles. — This tissue is much more abundant in the voluntary than in the involuntary muscles. To the former it gives an external investment, which sends septa into the intervals between the larger and smaller packets of fibres, and thus enables them to move in some degree independently of one another. The density of these general and partial sheaths is proportioned to the amount of pressure to which the organ may be subject, as is exemplified in the superficial muscles of the back, and in those superficial muscles generally where a fibrous aponeurosis does not exist. The areolar tissue does not usually clothe every individual fibre from end to end, giving it a cellular sheath, except in cases where the elementary fibres are of large dimensions. The areolar tissue, besides affording protection to the muscular fibres, admits of motions between them; and, by forming a connecting bond between neighbouring bundles, it must also serve the important office of limiting undue motions of one part of a muscle on another part. But a principal use of it appears to be that of furnishing a resisting nidus in which the delicate vessels and nerves can traverse the interstices of the fibres, and by which they can be protected from hurtful dragging during the unequal and oscillating movements of the fibres of a voluntary muscle in its state of activity. This idea is supported by the fact that scarcely any areolar tissue exists in the heart, or in the unstriped muscles generally. In the heart, though the contraction is powerful, it is instantaneous, or nearly so, and therefore probably more uniformly diffused, so that neighbouring fibres must be less moved on one another than in the more sustained contraction of a voluntary muscle. Moreover, the mutual intertwining of even the elementary fibres in this organ is in many parts of it so intricate, as to contribute much to their mutual support; and, in the other involuntary muscles, the contractions are slowly and evenly progressive along the fibres of the same set.

Of the Blood-vessels of Muscles. — The arteries and veins of muscles commonly run together: and most of the arterial branches, to within two removes from the capillaries, are accompanied by two *venæ comites.* They invariably pass more or less across the direction of the fibres, divide and subdivide, first in the intervals between the larger sets, then between the smaller sets, till the ultimate twigs insinuate themselves between the fibres composing the smallest bundles, and break up into their capillary terminations. In this course the vessels supply the areolar tissue, their own coats, and the attendant nerves. The capillary plexus of the areolar membrane consists of irregular but pretty equal-sized meshes, and contrasts strongly with that of the muscular tissue itself.

The *proper capillaries* of muscle are quite characteristic in their arrangement, so that a person, who has once seen them, can never afterwards mistake them. They consist of longitudinal and transverse vessels; the longitudinal always following the course of the elementary fibres, and lying in the intervals between them; the transverse being short communications placed at nearly equal distances between the longitudinal ones, and crossing nearly, or quite, transversely over or under the fibres. The manner in which the longitudinal vessels are placed in relation to the fibres, is seen in fig. 36, represented as they are seen on a transverse section. They usually occupy the interstice between three or more fibres, but sometimes also the space between the contiguous surfaces of two fibres. The length of the longitudinal vessels does not usually exceed the twentieth of an inch; in other words, the terminal twigs of the artery and vein pertaining to the same capillary are seldom further than that apart. The length of the transverse anastomosing capillaries necessarily varies with the thickness of the fibres over which they pass (fig. 36, B, *a'*).

The diameter of the capillaries of muscle varies, like that of others, with the size of the blood-particles of the animal. It is, however, only just sufficient to allow of the particles to pass. If a fragment of a frog's muscle, perfectly fresh, be examined, a series of blood-particles will be seen in the longitudinal capillaries. These particles are compressed and elongated, sometimes to a great extent, evidently by the narrowness of the canal which contains them. It may seem at first sight not doubtful that in the living creature these elastic blood-discs are similarly elongated in their passage through the vessels of muscle, but the admirable researches of Poiseuille will perhaps serve to explain this appearance without our being driven to suppose the presence of so formidable an obstacle to the capillary circulation through these organs. It is more probable that the contraction of the vessels, and the compression of the blood-discs, occur on the escape of some of their contents being permitted by the cutting off of the fragment for microscopic examination. The coats of the capillaries of muscle consist of a simple diaphanous membrane, in which a few irregular-shaped cyto-blasts occur at infrequent intervals.

Fig. 47.



Capillaries of a small fasciculus of muscular fibres from the neck of the Dog :—*a*. Terminal twig of the artery. *v*. Terminal twig of the vein. *p*. Plexus of capillaries. *e*. Elementary fibre, to shew the relative size and direction of those to which the capillaries, here represented, are distributed.

It results from this description of the capillaries of muscle, that their number must correspond nearly to that of the elementary fibres; consequently, that the same amount of muscular tissue, arranged as a large number of small fibres, would be supplied with a larger absolute number of capillaries than if arranged as a small number of large fibres. This difference of vascular supply is exceedingly remarkable, and will be reverted to in considering the contractility of muscle.

Of the Nerves of Muscle.—Nerves being the appropriate channel through which muscles are excited to contraction, we have now to inquire into the manner in which the two tissues communicate together. As far as is at present known, all muscles in the larger animals have nerves distributed to them; and, if we extend the inquiry to those extremely simple and minute muscles which have been already alluded to as existing in the smallest of living creatures, though we can no longer trace nerves, yet our inability to do so more probably depends on a corresponding simplicity of the nervous substance itself, so that it ceases to be anatomically recognizable, than on its entire absence. So general is the connexion of the two tissues, and so apparently indispensable for the subjection of the muscles to the purposes of the organism of which they constitute a part, that we may regard it as constant and necessary.

The distribution of the nerves through muscular structures has always been a subject of great interest with those who looked to this line of inquiry for some clue to the explanation, either of that wonderful active connexion subsisting between them, or of the nature of the contractile act itself. But though the anatomical results accruing from this inquiry are of a highly satisfactory kind, considered in themselves alone, yet they cannot be said to have hitherto contributed in any great degree to the elucidation of these mysterious questions. The best mode of inspecting the arrangement of the ultimate nervous twigs is, to select a very thin muscle, as one of the abdominal muscles of any small animal, or one of the muscles of the eye of a small bird, to steep it in weak acetic acid, and then to thin it out under the compressorium. The primitive tubules of the nerve may then be readily distinguished with a moderately high power. They separate from one another at first in sets, afterwards in twos, threes, or fours; and, if these be followed, they will be found ultimately separating from one another, forming arches, and returning either to the same bundle from which they set out, or to some neighbouring one (fig. 48).

Fig. 48.

Loop-like termination of the nerves in voluntary muscle.—After Burdach.

In this loop-like course they accompany to some extent the minute blood-vessels, but do not accurately follow them to their last windings, since their distribution is in a different figure. They pass among the fibres of the muscle, and touch the sarcolemma as they pass; but, as far as present researches have informed us, they are entirely precluded by this structure from all contact with the contractile material, and from all immediate intercourse with it. How then shall we explain the transmission of the nervous influence to a material thus enclosed? If it were wise or safe to go a single step in advance of pure observation on so abstruse a question, we might suggest, resting on the seemingly sure ground of exact anatomy, that this influence must be of a nature capable of emanating beyond the limits of the organ which furnishes it. But further than this, as to how, or to what extent this influence may so emanate, or as to what may be its nature, it would, perhaps, in the present state of knowledge, be hardly warrantable even to speculate.

The number of fibres in a muscle is always exactly proportioned to the power demanded, and their length to the amount of shortening required of them; but, these circumstances being secured, muscular parts are subject to great variety of form, being short, thick, or rounded, long, slender, or flat, according to their position relatively to particular bones, joints, other muscles, or the like. Thus, all are compactly knit and adapted to work in concert, without any mechanical interference with one another; and perfect symmetry, both of shape and action, is provided for.

We notice that the muscles are arranged on the skeleton in a great measure in sets, having opposite actions; as, for example, the flexors and extensors, pronators and supinators of the fore-arm. It is evident that the action of every muscle depends solely on its mechanical attachments, and that a tendon running round to a different side of a limb might quite reverse a given action. But we find that in general the muscles of the same set are designed to act together, not only by their attachment on the same side of a joint, but by a supply of nerves from the same source (congeneres). Yet even this can confer no special action of extension or flexion, but only an association of action which may be both at once; for example, the flexors of the toes extend the ankle, and the extensors of the toes bend it. Even a single muscle, the rectus femoris, flexes the thigh, and by the same action extends the leg. Muscles opposed in action are termed *antagonists*. This antagonism is in most cases required by the necessity there is for an active moving power in opposite directions; but it serves the important accessory purpose of elongating muscles when they cease to be contracted, as we see illustrated by the presence of elastic or some other force for the same purpose, when there is no antagonist muscle. When antagonists act together, the part is fixed.

The locomotive framework may be regarded as a series of levers, of which the fulcrum is for the most part in a joint, *i. e.* at one extremity, the resistance at the further end, and the power (or the muscle) in the intermediate portion. In most cases the muscles are attached very near the fulcrum, as in the familiar instance of the biceps, inserted into the tubercle of the radius. By this disposition, a contraction of a single inch in the muscle moves the hand in the same time through the extent of a foot, but then the hand moves through every inch with only the twelfth part of the power exerted in the muscle; *i. e.* a resistance at the hand equal to one-twelfth of the force of the muscle would stop its motion. Thus, force is converted into extent and velocity of movement, at the same time that the great inconvenience is avoided of having the muscles extended like bow-strings between the distant ends of jointed continuous levers. By the junction of two or more levers in one direction, as in the different segments of the extremities, the extent and velocity of their united actions are given to the extreme one. A blow of the fist may be made to include the force of all the muscles engaged in extending the shoulder, elbow, and wrist.

In the conspicuous example of the tendo Achillis, inserted into the os calcis, the resistance (or the weight of the body) rests on the astragalus, intermediate between the power and the fulcrum, which is here the ground, pressed by the ball of the foot. The extent and velocity of motion are here converted into power. If the tendo Achillis draws on the heel when the foot is off the ground, the front part of the foot is extended on the lower end of the tibia as a fulcrum, and exhibits an instance of the other of the three varieties of lever.

Of the Function of Muscles. — The great property of muscular tissue is that of shortening in a particular direction, and this property is called *contractility.* It is not that mechanical power which elastic substances possess of shortening themselves on the removal of some force which has stretched them, but it is an endowment, responsive to appropriate stimuli, and diminishing or disappearing with the healthy state of the tissue (p. 57).

The distinction between the contractility, the elasticity, and the physical tenacity of a muscle may be illustrated by the following imaginary experiment: Suppose the leg of an animal so severed from the trunk as to hang by a single muscle, which, after retaining its contractility for some time, were gradually to lose it. The limb would at first be borne up by the contractile power;

but, as that ceased, the muscle would elongate under the weight, and the limb would remain suspended simply by the tenacity of the part. If, now, the muscle were stretched between the hands, we should find it to possess some slight elasticity. The elasticity and much of the tenacity of muscles are attributable to the sarcolemma, and to the capillary and areolar tissues. It does not appear that elasticity is in any degree a property of the sarcous elements, and their tenacity must be comparatively slight: but it is the sarcous tissue alone that possesses contractility.

Although it is universally allowed that the muscular tissue is the contractile substance, yet the strange question has been raised, and is still warmly debated, whether it possesses this power in itself, and independently of all other tissues: some contending that nerve is necessary to confer contractility on muscle,—to charge it, as it were, with this property; others, that nerve is only necessary to call it into action; and others, that the property is the essential attribute of the tissue, and totally independent of all nerves. The time is past when the intricacies of this keen contest can be threaded with any benefit to the student, and we therefore refrain from attempting to follow them. We shall prefer offering him a view of the facts of the subject, as at present known, drawing our conclusions as they arise.

The contractility of muscle is exhibited in two varieties of contraction, passive and active.

Passive Contraction is that which every muscle is continually prone to undergo, by the mere quality of its tissue, as long as it remains in its natural situation in the body. The muscles are ever kept on the stretch by the nature of their position and attachments, and cannot have their ends so approximated, by attitude or otherwise, as that their tendency to shorten themselves shall cease. If, for example, the rectus muscle of the thigh have its extremities brought as near together as can be effected artificially by posture, they would yet be found to approach still nearer on being freed from their attachment to the bones. The stimulus to this contraction may be therefore considered to be that of extension. In fractures and dislocations attended with shortening of the limb, the muscles adapt themselves permanently to their shortened state by virtue of this property. This tendency to contract has been distinguished by the term *retractility*, from its being manifested by the retraction that occurs when the belly of a muscle is cut across. But, in this instance, the retraction would appear to be in part caused by an active contraction excited by the stimulus of the injury. It has been also styled *tonicity.* It is well exemplified in all those contracted states of muscles which follow paralysis of their antogonists, as when the features are drawn towards the healthy side in hemiplegia. The passive contraction of muscles is continually opposed to their elongation by the active or passive contraction of antagonists, and restores them when that subsides. By it they are accommodated to an attitude artificially given, when no muscular effort is required to maintain it. When no active contraction is present in a limb, the passive contraction remains; and being brought to a state of equilibrium in all the muscles, by their mutual antagonism, the limb is said to be at rest. This is the general condition during sleep, in which the posture assumed by the limbs is determined by the relative power of antagonist muscles: the flexors overcome the extensors, and hence the limbs are bent.

Active Contraction is attended with those striking manifestations of power that specially characterize muscle. It is always excited by a local or partial stimulus, and is always exerted in opposition to another force within the body, which it is able more or less completely to master. The opposing force is generally the passive contraction of antagonist muscles, as well as the weight or resistance of some part upon which the muscles act directly; but it may be the elasticity of parts, or, in the case of hollow muscles, the resistance of their own contents. Active contractions are also frequently opposed to one another in the maintenance of a fixed posture. Active contraction is partial and interrupted, both in extent and duration. It requires intervals of rest, being attended with exhaustion of the power which produces it; which exhaustion, in the voluntary muscles, is attended with the sensation called *muscular fatigue.*

The contractility of muscles, therefore, is being ever exerted, in obedience to the equable stimulus of tension, without fatigue, in the production of what we have termed passive contraction; when it is affected by a powerful, partially-applied stimulus, active contraction results, inducing the necessity for subsequent rest. But there seems no good ground for supposing the contractile force to differ in its nature, when exhibited under these different modes of action.

Stimuli to Muscular Contraction.—Whatever is capable of inducing contraction in the muscles, when either naturally or unnaturally applied to them, is termed a stimulus. In the living body, the muscular fibres are in most instances made to contract by the immediate influence of the nervous tubules distributed among them; and this influence, however called into play, should be styled the nervous stimulus, or the *vis nervosa*. This nervous stimulus, then, is simply the effect of such a condition of the motor nerves as enables them to induce contraction in muscular fibres which are in the due relation to their terminal loops. Of the nature of this condition, and of the mode of its production, we are as completely ignorant, as we are of the nature of all those other conditions of the nervous system on which the manifestation of its various phenomena depends; but we know some little of the agents by which the nerves are thrown into this state. The chief of them are volition, emotion, and impressions carried by the afferent nerves to the nervous centres, and there affecting the efferent, or motor nerves, independently of volition or consciousness; but to these are to be added various impressions from diseases and injuries of the motor nerves, either at their origin or in their course, together with pressure, heat, chemical substances, electricity, &c., applied to their texture. The former are the natural excitants of the nervous stimulus in the living body; the latter may be proved to possess this property by observation, and by experiments on nerves distributed to muscles, either in the body, or soon after their removal from it. The power of inducing contraction in the muscles is an endowment of those nerves only which have a certain organic connexion with the muscles; and these nerves are, therefore, distinguished as *motor*.

There are other stimuli of muscle besides the vis nervosa, which occasion contraction in the living body; but, in general, these affect only the hollow muscles. Experiment has, indeed, shewn these muscles to be under the influence of motor nerves derived from the spinal marrow; but it seems probable that some of them, at least, are normally excited to contract by the stimulus of stretching or distension, to which they are peculiarly liable from their arrangement as investments to hollow viscera. Muscles have not the capacity of elongating themselves that has sometimes been ascribed to them: when once contracted, they remain shortened, notwithstanding the contractile force have subsided, unless their ends be drawn apart by some extraneous force. This force is that which has been already specified as being always exerted in opposition to active contraction in the living body. In the case of the voluntary muscles, this force always continues to act after the active contraction has ceased; but in the case of the hollow muscles, where it consists of the resistance of their contents, it sometimes happens that these, when removed, are not at once replaced; and hence an enduring contraction, though the active contractile force is no longer exerted. Thus an empty intestine is reduced to the size of a tobacco-pipe, and the sphincters of the anus and bladder are kept contracted, without any tetanic spasm, or permanent expenditure of contractile force, as has been sometimes supposed.

Now, the stimulus of distension is, in the first instance, nothing more than the elongating force which calls into play the contractility of a muscle under its passive form; and there is this peculiar to it, that it affects equally every point of the substance of each fibre, which no other stimulus can do: and hence would result the uniformity which will presently be shewn to characterize passive contraction, for contraction is an answer to a stimulus. This consideration tends strongly to confirm the view which we have taken of the identity of the forces displayed in passive and active contraction, of *tonicity* and *contractility.*

Other stimuli may be mentioned as capable of causing muscular contraction by their direct agency on the tissue; but it is important to observe that these take no share in the production of natural contraction in the healthy body. It was long supposed impossible to observe the effect of stimuli on the muscular tissue when isolated from the nervous; and the fact, that the artificial stimuli which induced contraction when applied to a muscle itself, were the same with those which induced it when applied to the motor nerves, was considered sufficient proof that in the former case the effect was produced through the medium of nervous tissue still mingled with the muscular.

But this question has been brought to an issue by the positive observation that fragments of the fibre of voluntary muscle, entirely isolated from every extraneous tissue, whether nerve or vessel, may be made to contract in obedience to a stimulus topically applied to them. When such fragments are examined, they are found to contract first of all where they have sustained mechanical injury, viz., at their broken extremities; and, if water be brought into contact with them, it is absorbed, and thereby excites them to contractions, which commence at their surface.* The same thing is frequently

* Water has long been known as a rapid exhauster of the contractility of muscles. "Rigidity is produced almost instantaneously if warm water be injected into the arteries of a muscle. The flesh, under these circumstances becomes pale, increased in bulk, and suddenly hardens. The operation of

to be observed under a different form. A particle of foreign matter, as a hair or a piece of dust, may be included by design or accident in the field of the microscope, so as touch the side of a fibre at a single point. When this happens, the fibre will often exhibit a contraction, so plainly limited to the point touched, as to give unequivocal proof of its being the result of the irritation of pressure. Chemical substances may be seen to act similarly, if they be not so powerful as to destroy the texture of the part: and it is probable that electricity has a like agency. These interesting pheuomena may be observed more or less satisfactorily in all animals whose fibres retain their contractility for a sufficient length of time after removal from the body; and the crab and lobster will be found very favourably adapted for the purpose. In many reptiles, and fish also, the steps occur slowly enough to be adequately scrutinized.

The facts in question can admit only of one explanation, if it be conceded that the muscular tissue has been here separated from the nervous: and certainly that separation has been effected, unless the nervous tubules send off from their terminal loops a set of fibrils which penetrate the sarcolemma, and diffuse themselves through the contractile material within: a supposition for which there exists, at present, no foundation in the observations of the most diligent investigators of this subject. They will, therefore, probably, be regarded as conclusive proof that contractility is a property inherent in the very structure of muscle, and capable of being excited to action independently of the instrumentality of nerves.

An interesting phenomenon has been pointed out by Dr. Stokes, which, when illustrated by the foregoing observations, we may safely consider as an example of contraction in the living body in answer to a physical stimulus. In various cases of phthisis, and, indeed, in all cases attended with emaciation, a sharp tap with the fingers on any muscular part is instantly followed by a contraction, and by the rise of a defined firm swelling, at the point struck, enduring several seconds before it gradually subsides. This is often so prominent as to throw a shadow along the skin, and for the moment it might almost be mistaken for a solid tumour. That it is limited to the point struck is full proof of its being a direct effect of the irritation, and not produced through the medium of nerves; for

crimping fish consists in dividing the muscular fibre before it has become rigid, and immersing it in spring water. A small part treated in this manner contracts and hardens within five minutes."—Mayo, Physiol., p. 38. It exhausts contractility by inducing violent contraction, by which the fibre is often disorganized.

a contraction excited in the latter mode would be diffused over the parts to which the nervous twigs irritated were supplied, and would therefore frequently occur in parts at some distance.

Having premised these words respecting the stimuli of muscle, we proceed to consider what is known of the phenomena which attend the act of contraction. It is evident that the subject we are now approaching is one of primary importance; because, on the positive information regarding it, must chiefly depend our means of udging of the conflicting hypotheses of the nature and laws of action of the contractile force.

A muscle, when contracted, is firmer than before; but this rigidity is proportioned rather to the intensity of the contractile force exerted, than to the amount of shortening occasioned by it. The circumstance, however, has led to the belief, that the act is accompanied with a compression of the substance of the muscle into a smaller compass; but it is, on the contrary, well ascertained that it gains in thickness what it has lost in length. The experiments by which this fact is attested have been often repeated, and their general results accord well together. If a muscular mass be made to contract by means of galvanism in a vessel of water furnished with a very delicate tube, the slightest diminution of bulk would be at once indicated by the fall of the water within the tube; but the water, under these circumstances, is found to retain its level. Mr. Mayo varied this experiment by selecting the heart of a dog,* which, continuing to beat during some time, was in this way distinctly seen to undergo no change of size.

The familiar practice of accelerating the flow from the vein at the elbow, by desiring the patient to contract the muscles of the fore-arm, does not, as is sometimes imagined, shew any diminution of their bulk, but only a forcible increase of their lateral dimensions, by which the deep veins are compressed within the inelastic sheath of fascia, and the blood diverted into the superficial channels. In those muscles which have a bulging centre, or *belly*, as the biceps of the arm, the fibres are arranged in a curved form, and during contraction must tend towards a straight line in the direction of the axis of the muscle. In such instances, the blood-vessels that traverse their interstices must be in some degree compressed.

If we examine under the microscope the contracted state of a morsel of the sarcous tissue, we find it to present essentially the same characters as that of the entire organ, a shortening in length, with a corresponding increase in thickness; and this is true, how-

* Anat. and Phys. Comment., vol. i. p. 12.

ever minute the fragment may happen to be. This is all that can be said in general of the visible features of this remarkable phenomenon. Late investigations, instead of explaining the manner in which contraction is effected, by shewing its dependence on forces previously understood, have only served to display the inadequacy of the coarse and mechanical hypothesis that physiologists have been so prone to confide in, and to make it more than probable that they must ever be content to repose upon the fact above stated, as the simplest which the most refined microscopical analysis will ever disclose.

All muscle retains its contractility for a longer or shorter period after its separation from the body, or after death. During this period contractions may be excited by the nervous, and all other stimuli, which we can apply to it; and it is certain that these contractions are the same in their nature with those occurring in the living body under natural influences. Being also easy of inspection, they are admirably suited to the display of the minute changes occurring in muscle during its active state.

The muscle with striped fibres is peculiarly adapted for the display of these changes; for, its texture not being homogeneous, but marked throughout with perfect regularity into spaces of particles so minute as to require to be very highly magnified before they can be even seen at all, the anatomist is provided with the means of detecting movements, which, without this circumstance, must have remained concealed.

When a piece, retaining its contractility, is torn up into its elementary fibres, the fragments of these, when placed in water, are seen to undergo a slow movement at certain points, especially where they have suffered violence, as at their broken extremities. This movement consists of a shortening and thickening of the material composing the fibre, as is shewn by the general outline of the part, but especially by the appearances visible in its interior. The transverse stripes, both light and dark, become longer and thinner: in other words, the discs expand in circumference, flatten, and approximate to one another; or, to use another form of expression, the fibrillæ become shorter and thicker, both in the particles composing them and the material connecting those particles (fig. 49).

These changes are always local or partial; and it is most evident from the characters they constantly present, that they are not limited to any determinate regions, points, or segments, but occur indifferently wherever the exciting cause may chance to be exerted. Neither discs nor fibrillæ appear to have the smallest share, as aggregations of particles bearing those particular forms, in producing the phenomena of contraction. A contraction is never limited to a particular number of discs or fibrillæ, and is never accurately bounded by the interval between two discs. It constantly happens, that, at the edge of the contracted part, several discs are only partially engaged in it. A contraction, generally, when commencing at the broken end of a fibre, occupies its whole width there; but, when it commences at the border of the fibre, it may be confined to a portion of many discs: and, further, the contractile force is never exerted along the whole length of a fibre or fibrilla at once. A contraction excited in an elementary fibre by the contact of a hair extends into the mass equally in all directions, as we might suppose it would do, if the mass were homogeneous.

An attentive study of these interesting phenomena will lead to the conviction, that, in the bare fact of contraction, the *build* of the fibre is an item of no importance whatever: the exquisite symmetry displayed in the apposition of its component particles is, as it were, disregarded and overlooked; while the whole process is to be referred to the material itself, the ultimate tissue, whose property is *contractility*. This property appears to reside both in the particles and the substance connecting them.

The ultimate movements, therefore, on which contraction depends, whatever they may consist in, are molecula, and far beyond the reach of sense.

It will be perceived, that this view of the subject is the only one which can harmonize the fact of contraction in voluntary muscle with the same phenomenon in structures which have no complicated internal arrangement of particles, as, for example, in the unstriped fibre; and the contractility manifested by fibrine, immediately after coagulation, is a property too nearly allied to the contractility of muscle (a form of fibrine) not to give it additional credibility.

In regarding contractility, therefore, as a property of the living muscular fibre *in general*, it is meant that it resides in it as a property without which it would not be muscle; and in such a manner, that no particle, however microscopic, can be detached from muscle which does not of itself, and independently of the rest, possess this property as long as it possesses vitality.

Of the Differences between the minute Movements of Muscle in Passive and Active Contraction.

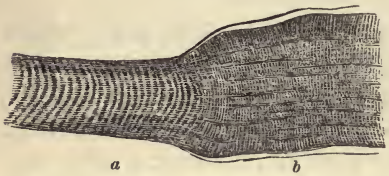
In *Passive Contraction.*—It is perhaps impossible, in the higher animals, to observe the nature of the microscopic movements occurring in muscle in its ordinary state or during its passive shortening; but, in the lower and smaller forms of life, this may sometimes be accomplished. It may always appear doubtful, however, whether any contraction that may be here witnessed be entirely of the passive kind, and consequently the movements here noticed are not worthy of implicit reliance. But it is more easy, and quite as satisfactory, to bring a muscle under inspection, which is still *in situ* and in equilibrium with its antagonists: in such, contractile force is being still exerted, though its full effects are prevented from taking place. This may be done in various small animals: perhaps the tail of small fish, or of the tadpole of the common frog, is the best adapted for the purpose. In the latter, deprived of its integument, we have obtained such a view, and have found the contraction to be quite uniform throughout, the transverse stripes being stationary and equidistant. This is nothing more than might have been expected on *à priori* grounds. The contraction, being the effect of the passive exercise of the property shared equally by all parts of the tissue, would be equal in equal masses; and, as the elementary fibres are of precisely equal width and substance from end to end, no part of them could predominate in action as long as only the equable stimulus coincident with their natural state of tension were applied. It may be concluded, therefore, that passive contraction is attended by a movement absolutely uniform throughout the whole mass of an elementary fibre, or of a muscle.

In *Active Contraction*, the case is far otherwise, as may now be considered proved by a considerable body of evidence.

It might be argued, prior to direct proof, that active contraction must be partial, at least at its commencement; because the stimuli which occasion it cannot, in their very nature, be applied to every particle of the fibre at one and the same instant of time.

Certain features of the phenomena witnessed under the microscope in fragments removed from the body, and contracting in water, have a close bearing on the present question. It has been already said, that such contractions are uniformly partial: but they present two further varieties, either remaining in the part where they first occur, or leaving it as they advance to others in the neighbourhood. The accidental circumstances under which the fragments are placed, explain these varieties. In the former case, the ends of the fragments happen to be freely moveable, and are drawn towards each other, according to the amount of contraction occurring in particular spots; and, as the contractile force leaves these spots and engages others, the ends continue to approximate, the parts once contracted remaining so, because there is no force to extend them. Hence the contraction appears permanent.

Fig. 49.

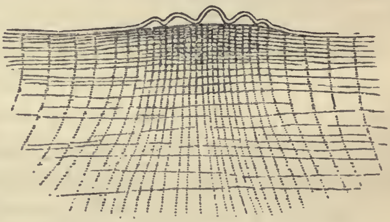


Fragment of an elementary fibre (from the Eel) partially contracted in water. Magnified 300 diameters.—*a.* Uncontracted part. *b.* Contracted part, along the border of which the sarcolemma is raised from the surface by the water that has been absorbed, and has thereby caused the contraction, and by it has been expelled from the contractile mass.

In the latter case, certain parts of the fibre (as its broken extremities) are fixed more or less firmly, so as to offer a resistance to the contraction that takes place; this resistance enabling the contractile force advancing to new parts to obliterate the traces of contraction in the parts in which it is subsiding, by stretching them. The ends usually become fixed in consequence of their being the first to thicken from contraction, and from their thus receiving the pressure of the lamina of mica or glass with which it is requisite to cover the object; and they are the first to contract, because irritated by being broken, and by the water, which is absorbed soonest where the sheath is deficient. This fixing of the ends brings the fibres in question nearly into the condition under which they exist in the living body, where it has already been explained, that there is always a resistance to be overcome in active contraction. This particular variety of the phenomenon, therefore, deserves special study. Those animals whose muscles are most tenacious of their contractility are the best suited for examination; and, among these, the young crab or lobster may be most easily obtained.

In an elementary fibre from the claw, laid out on glass, and then covered with a wet lamina of mica, the following phenomena are always to be observed. The ends become first contracted and fixed. Then contractions commence at isolated spots along the margin of the fibre which they cause to bulge. At first they only engage a very limited amount of the mass, spreading into its interior equally in all directions, and being marked by a close approximation of the transverse stripes. These contractions pull upon the remainder of the fibre only in the direction of its length, so that along its edge the transverse stripes in the intervals are very much widened and distorted. These contractions are never stationary, but oscillate from end to end, relinquishing on the one hand what they gain on the other. When they are numerous along the same margin, they interfere most irregularly with one another, dragging one another as though striving for the mastery, the larger ones continually overcoming the smaller; then subsiding as though spent, stretched again by new spots of contraction; and again, after a short period of repose, engaged in their turn by some advancing wave: this is the first stage of the phenomenon (fig. 50). At a subsequent stage, the ends of the fibre commonly cease to be fixed, in consequence of the intermediate portions, by their contraction receiving some of the pressure of the glass. The contractions, therefore, increasing in number and extent, gradually engage the whole substance of the fibre, which then is reduced to at least one-third of its original length.

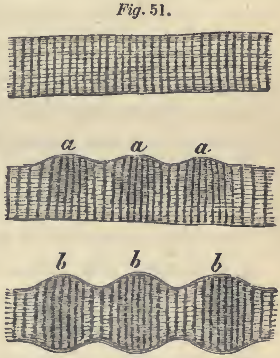
Fig. 50.



Border of an elementary fibre of a young Crab, shewing a spot of contraction, and the sarcolemma elevated in the form of bullæ by the expressed water.—Magnified 300 diameters.

The muscular tissue in these animals is comparatively tough; but, where it is more fragile, as in the frog, it may give way in the intervals between spots of contraction, and become ruptured and disorganized in various degrees.* In fishes we have seen a succession of phenomena similar to what has been described in the crab; waves of contraction advancing and receding, but gradually augmenting in bulk, till the whole fibre was finally contracted (fig. 51).

Fig. 51.



Stages of contraction seen on one occasion in an elementary fibre of the Skate. The uppermost state is that previous to the commencement of active contraction.

a. a. a. Successive "waves" of contraction seen moving along one margin of the fibre, marked by a bulging of the margin, by an approximation of the transverse stripes, and by a consequent darkening of the spots.

b. b. b. Similar "waves" still moving along the fibre, but engaging its whole thickness.

In all these examples, as long as the ends of the fragment are fixed, and will not yield to the convellent force, that force is seen to be exerted in a momentary manner in successive portions of the mass. In proportion as they yield to it, the resistance which enabled the contraction of new parts to stretch

* Phil. Trans. 1840, p. 490, pl. xix. fig. 75.

those from which it was receding is removed, and the appearances of contraction remain. A distinction is required between the contractile force and the contraction resulting from its exercise. The latter will be permanent, if no force from without be exerted to obliterate it by stretching; for a contracted muscle has no power of extending itself, there is no repellent force between its molecules. From these phenomena, therefore, it is possible to eliminate the appearances resulting from a subsided force, and to judge of the mode and duration of action of the force itself. Thus sifted, they prove that, even when directly stimulated by water after removal from the body, a muscle contracts in successive portions, never in its totality at once; and that no particle of it is capable of exhibiting an active contraction for more than an instant of time.

The appearances presented by muscle that has been ruptured by its own inordinate contraction in fatal tetanus, in the human subject, will supply the link wanting to connect the foregoing phenomena with those occurring in healthy contraction during life: for tetanic spasm differs from sustained voluntary contraction only in its amount and protracted duration, and in its being independent of the will; none of which circumstances are of essential importance in regard to the nature of the act of contraction itself.

The muscles are so arranged in the body, that no amount of contraction which the mechanism of the bony and ligamentous framework will permit one of them to undergo, can by possibility occasion the rupture of an antagonist, provided it remain relaxed: to be ruptured, the antagonist must be itself contracted. But a muscle, if contracted beyond its natural amount, may be so resisted by mechanical powers, in or out of the body, as to rupture itself. Hence, the contraction of a muscle is a necessary condition, and generally the essential cause of its own rupture: the other condition being a force greater than the tenacity of the ruptured part, holding its ends asunder; which latter may be either the active or passive contraction of antagonists, or mere mechanical resistance: but it is evident, that, for a muscle to be ruptured by its own contraction, that contraction must be partial, as is shewn in the case of the frog's muscle already mentioned.

An examination of muscle ruptured in tetanus is found to bear out these observations in the fullest manner.* The elementary fibres present numerous bulges of a fusiform shape, in which the transverse stripes are very close together. These swellings, or contracted

* Phil. Trans. 1841, p. 69.

parts, are separated from one another by intervals of various lengths, in which the fibre has either entirely given way, or is more or less stretched and disorganized. These appearances are met with after all contractility has departed; they are the vestiges of the spasm during life. Yet in other muscles, which have been likewise convulsed, but not ruptured, they are not found. Their presence is, therefore, the result of the rupture. They admit only of the following explanation: the contractile force has operated at the points found contracted, and by its excess, the intermediate portions have been stretched to laceration. Having once given way, the contracted parts have become isolated, and can no longer have been extended after the subsidence of contractile force; they consequently retain the form and appearances they possessed, when surprised, as it were, by the rupture, they have themselves produced, of the intervening parts.

Supposing, for a moment, that active contraction were an universal and equable act, and that, by the superior power of an antagonist, a weak muscle had been ruptured, the appearances resulting would manifestly be entirely different from those now detailed. The fibres beyond the ruptured point would have their transverse stripes uniformly approximated.

It may be concluded from the preceding facts,—1st. That active contraction never occurs in the entire mass of a muscle at once, nor in the whole of any one elementary fibre, but is always partial at any one instant of time:—2nd. That no active contraction of a muscle, however apparently prolonged, is more than instantaneous in any one of its parts or particles:—and therefore, 3rd. That the sustained active contraction of a muscle is an act compounded of an infinite number of partial and momentary contractions, incessantly changing their place, and engaging new parts in succession; for every portion of the tissue must take its due share in the act.

Two phenomena yet remain to be mentioned, which, by admitting of a satisfactory explanation on this view of the subject, give strong testimony to its correctness.

The first is the *Muscular Sound,* heard on applying the ear to a muscle in action. It resembles, according to the apt simile of Dr. Wollaston,* the distant rumbling of carriage-wheels; or rather, perhaps, an exceedingly rapid and faint tremulous vibration, which when well marked, has a metallic tone. It is the sound of friction,

* Phil. Trans. 1811.

and appears to be occasioned by those movements of the neighbouring fibres upon one another, with which the partial contractions must be attended in their incessant oscillations.

The other phenomenon is one whose existence has been recently ascertained by MM. Becquerel and Breschet,* viz. that *a muscle during contraction, augments in temperature.* They have found this increase to be usually more than 1° Fahr.; but sometimes, when the exertion has been continued for five minutes, (as the biceps of the arm, in sawing a piece of wood,) it has been double that amount. This development of heat may be in a great measure attributable to, and even a necessary consequence of, the friction just alluded to.

Thus it would appear, that in active contraction there is a disturbance of the state of equilibrium, or rest, by the application of a special stimulus to certain portions only of each fibre; by which first these portions, then others in succession, are made to contract strongly, and to pull on the extremities of the fibre through the medium of the parts not so contracted. The contractions undulate along the fibre from the point stimulated, and there is always a considerable part of each fibre uncontracted. This will account for the remarkable fact, that detached fragments of the voluntary fibre will contract by two-thirds of their length; though an entire muscle, in its natural situation, cannot shorten by more than one-third. This great capacity of contraction in the *tissue* would be without a purpose, if it were not that it only admits of momentary exertion, and therefore requires that in the *organ* successive parts should take up the act, and by so doing, render it, as a whole, continuous. In an active fibre the contracting parts are continually dragging on those in which the contractile force has just subsided, and which intervene between them and the extremities of the fibre. These are thereby instantly stretched, and come to serve the temporary purpose of a tendon; but one which resists extension more by its passive contractility than by its mere tenacity. It is these parts which in tetanic spasm suffer laceration; which happens in consequence of the contraction excited by the vis nervosa being then too powerful to be resisted by the passive contractility.

The preceding account of the minute changes occurring during contraction rests on data furnished by the striped form of muscular fibre; but there is nothing contained in it which seems at variance with the little that is positively known regarding the contractions of

* Recherches sur la Chaleur Animale. Archiv. du Muséum, tom. i. p. 402.

the other form. The differences between the contractions of the two varieties are almost certainly confined to the manner of exercise, and do not extend to the essential nature of the act. Though the unstriped fibre has not been studied by the microscope, during its active state, with the same success as the other, yet the similarity of the gross changes observed in it by the naked eye, to those seen in voluntary muscle, forbid us to doubt the identity of the phenomenon in all that is essential to it as an act of contraction.

From the knowledge we possess, we are perhaps entitled to hazard some further conjectures respecting the differences in the mode of exercise of the contractile power in different cases. In whatever that mysterious power may consist, it would appear that the structural modifications of the two kinds of fibres are intimately connected with the manner in which it is capable of being exerted. Whenever the striated structure occur, we witness an aptitude for quick, energetic, and rapidly repeated movements; while, where it is deficient, they are sluggish, progressive, and more sustained.

The varieties in the character of contractions performed by striated muscles are very striking, especally that of the heart, as compared with the prolonged action of the voluntary muscles. In both, there is an alternate momentary action and repose of every contractile particle: but in the heart the contraction is universal at one instant, and the repose equally universal at the next; while, in the prolonged action of the voluntary muscles, contractions of certain parts of each fibre always co-exist with repose of other parts.*

The contractions of voluntary muscles differ greatly from one another in duration, energy, and extent. Dr. Wollaston† was of opinion, that the phenomenon of the muscular sound affords a proof that the *duration* of a muscle's contraction depends on the application to it of a succession of distinct impulses; and this idea, according very nearly, as it does, with the latter evidence of observation, appears, on the whole, the most satisfactory that has been advanced on this abstruse subject. He also thought that the intensity of a contraction corresponds with the rapidity with which these impulses are transmitted to it; and this likewise may be, in part, true. But there is, in addition to this, in all probability, a difference in the intensity of the stimulus itself in different cases, producing a

* By the expression "universal at one instant," we do not mean *absolutely* so; for observation, and the presence of the muscular sound, both declare that the contraction, even of the heart, though so apparently momentary, is progressive.

† Philos. Trans. 1811.

difference in the size of each wave, a difference in the amount of contractile energy exerted in each, and a difference in the rapidity with which the waves oscillate along the fibre. The *extent* of the contraction (the duration and intensity being the same) will manifestly depend on the amount of the length of the fibre which is contracted at once; but we are ignorant whether this variation in amount is effected by a variety in the number of waves, or in the extent of the fibre engaged by each of them.

In describing the white fibrous tissue, we remarked the facility with which its fibres are thrown into a wavy or zigzag course when their ends are brought near together. The same thing occurs in the nerves, and may be observed in almost any flexible non-elastic cord. The muscular fibre easily assumes this zig-zag course, when its ends are approximated by any other force than its own contractility. It may thus be at any time thrown into zigzags, long after it is quite dead, and has lost all its contractility: and, in general, such zigzags occur at pretty regular intervals, determined by the force employed, and the flexibility of the tissue; and, when several fibres are lying in contact, their zigzags usually correspond.

Now, such zigzags have been frequently observed in the living fibre, of course accompanied with an approximation of its extremities; and some physiologists, mistaking the effect for the cause, have concluded the zigzags to have occasioned the shortening. Dr. Hales, and, long after him, Prevost and Dumas, examined this appearance in the flat abdominal muscle of a frog, laid on glass, and made to contract by a galvanic shock; and, noticing that the angles of the zigzags corresponded in many places with the transit of nerves across the fibres, they concluded that an electrical current, passing from one to the other, occasioned the flexion of the fibres at the points of contact.

This hypothesis, when first proposed, attracted great regard, from its appearance of simplicity, and from its falling in with the then favourite notion of the identity of the nervous influence with some form of electricity; and without sufficient caution it was very generally adopted. The facts previously stated, however, completely overthrow it, and render an explanation of the causes of the error scarcely more than historically interesting. It would appear that the galvanic shock, when passed through a mass of fibres, affects them unequally, some only being contracted by it: but these, by their cellular and vascular union with others, draw towards each other the ends of the uncontracted ones, and, of course, throw them into zigzag; and it is most natural that the passage of nerves or vessels across them should determine the flexures to take place at this or that particular point. When some fibres are straight and others zigzag, and yet the ends of all equidistant, it is clear that the straight ones are the short or contracted; the zig-zag, the long or relaxed. So, also, when a living muscle is laid bare *in situ*, the air excites tremors and a zigzag appearance on its surface, by the different fibres taking on non-simultaneous contractions.

Schwann* contrived an apparatus by which he could estimate the varying force of contraction which a muscle could evince under the same stimulus, (an electric shock of a given power applied to the nerve), when its length was varied by its passive contractility being balanced by different weights. He sought to discover whether the contractile force was increased as the contracting parts approached each other more nearly. If he had found it so augmented, there would have been some reason for connecting contractility with the other forces of attraction with which we are acquainted, the power of which increases with the nearness of the points attracted, in the ratio of the square of the distance. But the result of several ingenious experiments were quite opposed to this notion; proving that, within certain limits, the power of a muscle to contract under a stimulus is greater in proportion as it is less contracted, and that it diminishes as the amount of contraction increases.

Considering, as we are perhaps entitled to do, that an equal mass of each fibre, say one-third, was in contraction at any one instant by each application of the stimulus, we may reduce the result of these experiments to an estimate of the passive contractile power under different amounts of stretching; for then the varying amount of aggregate shortening under the same stimulus would indicate the varying amount of resistance to elongation afforded by the intermediate two-thirds to the same amount of active contractile force in the one-third.

It is clear, from that which precedes, that contractility is a property residing in the sarcous tissue by virtue of its chemical constitution, and that it is capable of being called into action by other stimuli besides the nervous. That it departs with life, is a proof that those actions of waste and nutrition, concomitant with the flux of life, are essential for its integrity. We know that contractility is exhausted both by disuse of a muscle, and by over-use consequent on over-stimulation; and in no other way can these opposite causes act than

* Müller's Physiology, by Baly, p. 905.

by their both interfering with healthy nutrition. That they do thus act, is rendered probable by other proofs. It has long been known that cutting off the supply of blood from a muscle destroys its contractility; that unnatural temperature has the same effect; and, in general, that all causes affecting nutrition affect also contractility in the same degree.

The contractility of a muscle has also invariably a certain complexion or character connected, we might almost say, with the vigour, but at least with the character, of the nutrient process in the particular muscle. This fact has been ably illustrated by Dr. Marshall Hall,* who nevertheless is opposed to the great conclusion which we consider to flow from it, that contractility is proportioned to the activity and perfection of the nutrient function.

If we suddenly check the supply of nutrient material to the muscles of various animals, in the same state as regards previous stimulation, and in such a manner as not to stimulate the muscles in so doing; we shall find that their contractility, as evidenced by their contracting under a given stimulus, endures through very unequal periods of time. Thus, in the bird it is very evanescent; in the insect, also, it is very evanescent; in the mammal less so; in the reptile it lingers longer; while in the fish and crustacean it is in general very enduring.

The degree in which oxygen is admitted to the tissues in these animals, corresponds in the main with the scale thus designated by the relative endurance of the contractility of their muscles. Nothing is more probable than that the amount of oxygen admitted to the tissues may be taken as a fair estimate of the activity in them of the processes of waste and assimilation. Now, we know that the vitality of the tissues does not cease immediately on their supply of nutriment being cut off; that death of the whole animal, as an individual, is not necessarily attended with simultaneous death of every part; that *somatic* death gradually follows *systemic* death, from the functions being no longer concatenated in mutual dependence: and it is entirely consonant with facts, to suppose that the endurance of the vital functions in the tissues after systemic death is proportionate to the slowness with which they are ordinarily performed. The close correspondence, therefore, between the duration of contractility and the slowness of the nutrient function in various animals, is a strong evidence of the dependence of the one on the other.

* See article "Irritability," Cyclop. of Anat. and Phys.

And it is extremely interesting to observe, that not only does a less arterial character of the blood co-exist with a more enduring contractility, but also that there is less of it supplied to the muscles, for the above scale corresponds also with that in which animals are ranged in regard to the size of the elementary fibres; and we have already seen that the vascularity of a muscle is inversely as the thickness of its fibres.

Thus we have animals ranged in the same series, whether we estimate it by the duration of contractility, the degree of the oxygenation of the blood and tissues, or the quantity of blood sent to the muscles, viz., birds, insects, mammalia, reptiles, fish, and crustacea. The meaning of this correspondence may be further illustrated by the phenomena of hybernation, in which all functions are held enchained, and we are certain that nutrition proceeds with extreme languor. In the hybernating animal, contractility is very enduring, as compared with that property in the very same organs when in a state of greater vital activity.

Nor must the evident relation subsisting between fibrine and the sarcous tissue, in respect of their vital properties, be passed over in silence. In chemical constitution they may be said to be identical; and there seems no doubt that muscle is formed by the direct deposition in a solid form of the fluid fibrine of the blood, under the elective attraction of the previously existing tissue. Now, in birds, the blood, *i.e.*, its fibrine, coagulates, or assumes the solid form, very quickly when it is withdrawn from the vessels, in mammalia less so, and in reptiles and fishes very tardily, if in these several cases it be placed in similar circumstances. A fatal stroke of lightning, which instantaneously destroys contractility in the muscles, prevents also the coagulation of the blood. In the same person, under health and disease, the blood may vary much in the speed with which it coagulates, according to its chemical constitution, the amount of oxygen accumulated in it, and the activity of the vital processes: and, after death, the coagulability of the blood, and the contractility of the muscles, have a general correspondence, which has been even made the basis of an hypothesis, ascribing the *rigor mortis,* or the dying act of contraction, to coagulation of the blood.* It will be subsequently explained† that the fibrine of the blood, on becoming solid, acquires for a brief period the property of contractility;

* Orfila, Béclard, and Treviranus hold this view, which Müller seems to regard as not untenable.

† See chapter on the Blood.

and this in very different degrees, according to varieties in the same causes which affect the speed of its coagulation. No one will pretend that this is not as much a property of living fibrine when solid, as that of coagulating is of the same substance when fluid; and the correspondence between the coagulated living fibrine of the blood and the living sarcous tissues in chemical constitution, in the possession of contractility, and in the modes in which that vital property in both is affected by similar causes, adds strong confirmation to the opinion we have expressed, that contractility is a property of the living muscular substance as such.

But contractility does not vary in its durability alone; it also presents great differences in regard to its *aptness to excitation* by stimuli: and it would appear that these characters are always *cæteris paribus*, in an inverse relation to one another. In birds and insects, which have for the most part to sustain themselves by very energetic and rapid muscular movements in the air, the excitability is extreme; and certainly the motions performed by these creatures far exceed in precision, regularity, and frequency those of any other animals.

The *rigor mortis*, or stiffening of the body after death, is due to a contraction of the muscles. If the contractility of a muscle be enduring, the rigor comes on late and lasts long; but if it be evanescent and its character excitable, the rigor begins very soon and quickly terminates. This is true in different individuals and classes of animals, and corresponds entirely with what we have already said of the varieties of this property. Its cause is obscure, and may be complex; but its resemblance to the contraction of fibrine after recent coagulation is too obvious to be overlooked. Its nature is shewn by the preceding observations (p. 180).

We have the power, at will, under certain limitations, of producing, checking, and regulating the amount of contraction in the voluntary muscles; and, as a necessary part of this power, we are able to appreciate, by certain sensations originating in the muscles, what precise degree of contraction is present in each. This latter is only that modification of common sensibility which belongs to muscle. It has been termed the *muscular sense*. In it we possess a most important aid to the sense of touch, being able accurately to vary the position and amount of pressure on external objects in voluntary accordance with the impressions these communicate to the sensorium through the tactile nerves; and by it we are able to estimate with nicety the amount of muscular power required to balance various resistances, as weights, &c. In general, these resistances must be brought into relation with the muscular sense through the organ of touch, which is adapted to this purpose by its superficial position on the body. But the powers of the muscular sense, isolated from tact, are exhibited, in its enabling one to estimate the weight of a tumour developed in the interior of the limb, and in general the resistance afforded by the weight of one part of the body, or the action of one muscle or set of muscles, to that of another. Hence a principal source of the marvellous power which all animals possess of associating the various parts of their bodies in numberless combinations of harmonious movement.

Of some Varieties of Muscular Movement. — Having described the differences between the movements of active and passive contraction, we shall now be more able to refer to their proper causes those varieties of movement by which certain muscles or classes of muscles are distinguished. In briefly adverting to these, we shall have to glance at some collateral considerations regarding the mode of their connexion with the nervous system, which cannot be fully understood without reference to what will be afterwards said under that head.

The *Action of the Sphincters* of the anus and bladder seems, at first, peculiar. They are constantly contracted, except during the passage of the contents; and yet no fatigue attends this persistent action. The explanation is very simple. They remain contracted unless the contained matters are forced within them by a superior power. Now, their mass, and therefore their contractility, is superior to that of the wall of the cavity above; consequently their passive contraction endures while that of the parts above is being gradually mastered by the accumulation of the fæces or urine. But, when these excretions at length excite active contraction in the walls of the cavity containing them, this overcomes the passive contraction of the sphincters, and the evacuation occurs. The sphincters have striped fibres and voluntary nerves, by means of which we can for a time add active to passive contraction, and thus retard the expulsion; but, as the accumulation proceeds, this power is diminished or lost, and the sphincters yield. The levator and sphincter ani frequently aid the accumulation of the fæces by temporary active contractions, by which the fæces tending to dilate the sphincter are pushed backwards for a while. The rectum is thus preserved empty until the period immediately preceding defæcation.

In paralysis of the lower part of the body from disease or injury of the spine, the voluntary power of the sphincters is lost, and the fæces and urine pass involuntarily. But this is no proof, as is commonly imagined, that the ordinary contraction of the sphincter is an active one, performed in obedience to a continuous nervous stimulus. The difference is, that it can now induce no active contraction through the nerves, to counteract temporarily, and in obedience to the will, the active contractions of the parts above, which are not under the influence of volition, and are not paralysed. Hence, whenever the fæces are driven against it, it gives way, against the patient's will, and (if the sensitive nerves are also paralysed) without his knowledge.

Contractions are called *peristaltic* or *vermicular*, which advance through a muscle in a slow and progressive manner. When analysed closely, we shall find that they are only a variety of the active contraction already described. If a number of striped fibres are arranged in a long series, and are contracted in succession (as in caterpillars), the resulting movement is vermicular: but in the higher animals it is only in the hollow unstriped muscles that this variety of contraction occurs; and the best example of it is in the alimentary canal. On laying bare the intestines of an animal just killed, we observe successive waves of contraction advancing down the tube, and urging its contents along. They appear to be rendered more active by the contact of the cold air; but may be re-excited, when they have almost subsided, by irritation of the sympathetic ganglia, from which the muscles are supplied with nerves. If a single point of the intestine be touched, a contraction presently occurs there, which moves onwards to a considerable distance, and is often succeeded by others spontaneously arising.

It is impossible not to remark the close similitude between these contractions and those visible by the microscope in the striped elementary fibre. We have here on a large scale the wave-like character there exhibited. A contracting voluntary muscle exposed to view exhibits a tremulous motion, and it may be a question how far this may depend on numerous contractions strictly vermicular, affecting successive sets of fibres, but prevented, by their irregularity and want of coincidence through the whole muscle, from appearing so to the eye. When the pectoral muscle is struck, a knot-like contraction often moves off in a slow manner in the direction of the fibres. Peristaltic contraction is coincident in a large number of contiguous fibres; and its progressive character is more easily perceived in consequence of the arrangement of the fibres around a compressible cavity. The contraction appears more sluggish than other forms; but, as we are ignorant of the length of each unstriped fibre, we cannot say whether this slowness is in advance along each one, or merely from one to another.

The contraction exhibited by the muscles in question is always of the peristaltic character, by whatever stimulus excited; and its type is therefore probably derived from some peculiarity in the fibres themselves, as in their arrangement. But it is remarkable that the stimuli which usually excite it, are applied in succession to different parts, and are thus entirely suited to the production of the peristaltic contraction. We have a striking example of this in the œsophagus, which is simply a tube of transmission, and not intended to delay the food. The pellet, when thrust into it by the muscles of the pharynx, distends its fibres; which, then contracting upon it, propel it into a fresh portion ready to receive it. This in its turn contracts, and urges it along; and so on, until it is conducted to the stomach.

In this instance, it is evident that the propelled substance is itself the stimulus to the successive contractions. This it may be, either by distending the fibres, and so acting locally upon them; or else by impressing the nerves of the membrane touched, in such a way as to excite a nervous stimulus to the muscular coat at each particular part, at the proper moment. As the food is not propelled if the nerves are divided, there can be little doubt that the latter is the true explanation.

The contraction of the bladder occurs after a gradual distension, and, though very temporary, is probably of the true peristaltic kind. The more protracted action of the *uterus* is undeniably so. In pregnant animals this may be as distinctly perceived as in the intestines, and it probably occurs during the gradual development of the muscular structure as pregnancy advances; but at length a very powerful impulse occasions the expulsion of the young, and the uterus subsequently remains contracted, because no force distends its fibres. The *after-pains* mark the final efforts of active contraction. Atrophy of the tissue then occurs, as its development had done, in accordance with other laws.

Rhythmical contractions are those which succeed one another after regular intervals of repose. The muscles of respiration and the heart exhibit them through life, which would cease if they were intermitted even for a brief period; for the oxygenation of the blood, and the dispersion of that fluid through the substance of the various organs, must incessantly proceed. Hence neither is an act of the will required for their production, nor could it under any circumstances prevent them. The heart beats independently of our consciousness or controul; but the respiratory action may be hastened, or retarded, at will, though not stopped. This voluntary power is given because these muscles are required in various movements of the body, either alone, or in aid of others; they minister to other functions besides that of respiration. The voluntary, or irregular action, however, is entirely subordinate to the involuntary and rhythmical.

The rhythmical character of the respiratory act is to be explained by reference to the stimulus by which it is ordinarily excited. This is an impression made on the internal surface of the lungs by the deteriorated air, and recurs periodically from the change induced in the inspired air by its contact with the blood in the air-cells.

Though the heart is in no respect under voluntary influence, yet emotional and instinctive impulses easily affect it: its action is throbbing, tumultuous, or feeble. These impulses act through the cardiac nerves, which, if stimulated mechanically, will excite contractions in a heart removed from the body, and which has almost ceased to beat: but, under all circumstances, the action of the heart is rhythmical. The cause of the rhythm it is exceedingly difficult to resolve. This variety of contraction is coincident with periodic distension of the cavities, and impressions on their lining membrane. But it continues long after the heart is empty, and its nerves cut. Hence, whatever share these circumstances may have in giving the rhythmical character in the natural condition of the parts, they are certainly not essential to each individual pulse. It is singular that a mechanical stimulus applied once to the heart will often excite a series of contractions after they had ceased, or modify the rhythm of those previously existing; its effects being thus prolonged through many beats.

In reviewing the actions of the voluntry muscles, we may remark the following interesting circumstances:

1. *As to Association of Movements.*—By the mechanical arrangements of the muscles on the bony framework, and by the peculiarity of their several nervous connexions, they are rendered capable of conspiring in those combined actions which produce the various attitudes and general movements of the body. There are few muscular actions indeed of an entirely solitary kind. In the animation of the features under the passions, in articulation, in deglutition, in respiration, and in numberless other cases, we have examples of this association of many actions to the production of

one effect. Even the consent of the fibres of a single muscle in contraction is an instance of this fact. Among innumerable other proofs of harmonious design in the construction of the animal body, this might be singled out as a most convincing one, that not only are the hard levers, and their joints and motive engines, so built up as to be entirely proportioned and adapted to one another in shape, strength, and position, and a system of nervous communications established, by which the motor power can be at one excited, prolonged, or controuled in any particular muscle; but that the mere will, an emotion, an excitement of sense, or even one unconsciously received, is able, by the correspondence existing between the different parts of the nervous system, to produce associated actions in precisely those parts mechanically adapted to move in concert, and this with exquisite exactitude as well as variety.

Such is the nature of the nervous communications between certain muscles, that in numerous instances, one cannot be stimulated to contraction without others contracting of necessity at the same time. This depends very generally on the mechanical dispositions of muscles, obliging certain of them to fix a point from which others may act. Thus the scapula is continually being fixed by the muscles connecting it with the trunk, in order that the arm may be wielded upon it. Thus, also, the brow cannot be elevated by the frontalis without the occipitalis fixing the intermediate tendon. But, in other instances, this necessary consent is dependent on the symmetrical arrangement of similar parts on the two sides of the body. Some persons cannot close one eye keeping the other open; or dilate one nostril without the other; we cannot look up with one eye, and down with the other; nor compress the abdominal cavity by the muscles of one side without those of the other. There is, indeed, a general tendency to symmetrical movement, which it is the part of education and habit to overcome within certain limits. The movements of the hands — those wonderfully versatile instruments of man's intellect — are, in his state of infancy, generally symmetrical. The unsymmetrical actions of walking are a slow acquisition. Most motions that are symmetrical are also harmonious; but there is one example in which *symmetry* gives way to *harmony* of movement, viz., in the lateral motions of the eyes, where symmetry would produce a squint, and derange the consent of the images on the two retinæ. Here, therefore, by the distribution of the nerves, non-symmetrical muscles are made to produce a harmonious movement.

The various attitudes of man may here be briefly explained.

Muscular actions associated to produce an attitude are styled *co-ordinate.* They conspire in obedience to the particular organization of the nervous and muscular systems; and the resulting postures are natural, and perfectly accordant with the wants and habits of the species. Most attitudes, if perfectly natural, are graceful, just as external figure is graceful; unnatural attitudes are more or less constrained, or awkward. The co-ordinate, like other movements of the voluntary muscles, are liable to be influenced by passions and affections of the mind. Hence the internal commotions of the soul betray themselves in the attitudes of the body as surely as in the lineaments of the countenance.

In considering the different attitudes, it is to be remembered that the human body is not withdrawn, either by its organization or vital endowments, from the operation of the general laws of matter; and, accordingly, that the muscular actions occurring within it are all adapted to act upon its several parts, as upon masses of certain shapes, sizes, and weights. In all attitudes the centre of gravity must be maintained within the base of support.

In *standing*, the base of support is the space included between the extreme points of the feet. The feet are separated, and the toes turned outwards to increase it. If the body be pushed aside, the foot is instantly carried under it, or it falls: and if motion be unexpectedly given to the feet, while the body remains at rest by its inertia (as when a boat in which we are standing is suddenly shoved from off the shore), the body falls. In standing upright, both legs are kept extended, and the spine and head erect; if the muscles that effect this be suddenly paralysed, as when a man is shot dead, the head droops on the chest, the curves of the spine are increased by the pressure of the superincumbent weight, and the whole trunk approaches the ground by bending the joints that were before extended.

The muscular action required to maintain the erect posture of the body is very great. This is shewn by the fatigue that ensues on an attempt to remain perfectly still in the erect posture, even for a very short time. In fact, though we can stand long at a time, it is only by frequently relieving one set of muscles, and bringing another into play, as every one may convince himself by attention to his own case. We throw the weight of the body first on one leg, then on the other; we change the position of the feet, and of the ankle, knee, and hip joints, as well as of the rest of the body.

Under all these movements, the centre of gravity has to be kept within the basis of support; and, to effect this object, the different muscular actions on which the erect posture depends must be exquisitely balanced against one another, and, when one is altered, the rest must be readjusted in harmony with it. In the practised tumbler, balancing himself on a point, or the opera-dancer, poised on a single toe, we have the most beautiful examples of the precision of this adjusting power. Where the basis of support is ampler, it is less apparent, but not less real.

The various parts of the body are *weights*, and, in the muscular adjustments, are treated as such. By their symmetrical development on the two sides, they are naturally balanced, and thereby carried with less muscular effort. When two equal artificial weights are fixed on opposite sides of the body, equidistant from the centre of gravity, (as when buckets are suspended from a bar passing across the shoulders,) the mere weight is all that the muscles have to support: but, if one be removed, a corresponding inclination of the body must instantly be made towards that side to counterpoise the other; and for this a sustained muscular effort must be made in addition to that required for the support of the remaining weight. Now, a part of the body on one side (say, an arm), by being carried from the centre of gravity, may disturb the equilibrium of weight, just as moving the weight on a scale-beam disturbs it; that side of the body becomes relatively heavier, and an inclination towards the opposite is rendered necessary. In all the changes of attitudes, similar adjustments are being constantly made; and, in general, the more accurately they are effected, and the more œconomically in regard to the outlay of muscular power, the more graceful and pleasing are the movements and postures themselves.

In the associated *movements of progression*, or locomotion, the same circumstances are observed: walking, running, and leaping are but different modes in which the body is repeatedly inclined by muscular effort beyond the basis of support; and this basis brought again and again, by muscular effort, under the centre of gravity.

The movements of ordinary *walking* may be readily analyzed. Suppose we commence by advancing the left leg. We first slightly raise the left heel, and bend the left knee, to disengage the limb from the ground; throwing the weight of the body on the right limb, and, therefore, inclining the body towards the right side. The body is now raised by an extension of the right ankle-joint, effected chiefly by the calf; the ball of the foot resting on the ground, which serves as a fulcrum. At the same time the body is thrown in advance of this fulcrum, and would fall, were it not that the left leg is now brought under it, and receives its weight, by which the body is in turn inclined to the left. The right leg, which had been extended, is then bent, raised from the ground, and swung forwards, ready again to sustain and project the body, when the left leg has gone through a similar movement. In *running*, the muscular actions are performed in a similar succession, but more rapidly and more vigorously. The body is more bent forwards, and its weight made more effectually to aid progression. In *leaping*, the body is projected by a sudden extension of both the lower limbs, and raised, for a brief time, entirely from the ground, the feet being advanced again in time to receive its weight as it descends.

2. *As to the Manner in which Movements of the Voluntary Muscles are excited.*—These muscles are subject, through the motor nerves, to the influence of several remote stimuli, already enumerated, and the chief of which, *volition*, gives its name to the class. These stimuli, in the healthy body, impress the motor nerve in the nervous centre, and the effect is a contraction of the muscle. By an exertion of the will we can contract more or fewer muscles at once, and to any degree, within certain limits: we can contract antagonist muscles together, or alternately, and through a longer or shorter period.

But every voluntary muscle is subject to other influences more certain and more powerful in their operation than the will, and to which the will has often to yield. The wonderful and characteristic movements of the body, and especially of the features under the impulses of passions and emotions, are all involuntary, of which the best proof is to be found in the very partial power the will has of restraining them. To imitate the movements of passion is a task of extreme difficulty; and those actors succeed the best who lose themselves the most in their characters, that is, who the most completely assume for the time the passion they design to pourtray. Without this quality the most elaborate imitation is cold, and fails to touch our sympathies. The genius of the histrionic artist consists chiefly in this power.

Many movements ensue involuntary when certain impressions are made on the surface of the body, or in any part of its interior, either by external or internal causes. Such impressions are usually attended with consciousness, but sometimes not; so that there is no reason to believe that perception of the impression is in any way essential to the production of the movement. All such movements are termed *reflex*. The contraction of the œsophagus in swallowing is an example of them without consciousness. The sudden inspiration that follows a dash of cold water on the skin, and the writhings produced by tickling, are instances attended with consciousness. All muscular actions consequent on pain, and which are not the immediate act of the will, are similar in kind, though the stimulus producing them is unnatural.

Reflective movements are sometimes called *instinctive;* but this term is better limited to actions resulting from a propensity in the mind, of the meaning of which we are ignorant, but which we follow blindly without reference to consequences. Such propensities are developed in animals much more than in man; and in man more during his infancy than in his mature state, when reason asserts her domination over instinct. Instinct exhibits foresight; but it is the foresight of the Creator, and not of the creature. It is the reason of God working with the material instruments of the creature's reason, independently of the creature's will. Hence the movements consequent on its impulses have all the concatenation and character of movements impelled by reason through the will; while they are altogether independent of the will. Instinctive movements approach the most nearly to voluntary ones.

Thus passion, emotion, reflected stimulation, and instinctive impulses will all excite involuntary movements of the voluntary muscles; but, in the natural state of the body, all these causes are found acting in harmony with one another, often conspiring to produce the same movement. The power of the will to controul them is but slight, and in some cases null. It differs with the original strength of that faculty, with the temperament of the individual, and especially with the degree in which it has been affected by habit. The power of this law is in nothing more conspicuous than in its influence over the human will. A frequent and energetic repetition of voluntary acts of controul over the involuntary movements of passion, emotion, and instinct, is invariably followed by an increased power of controul, and *vice versâ.* This also extends (but in a less degree) to those movements of voluntary muscles, consequent on reflex stimulation, which are not essential to life.

When movements, which have been at first voluntary, come to be performed more or less unconsciously, they are styled *mechanical.* A thousand instances of them might be given; *all voluntary* ones becoming more or less so by *habit.* The nervous paths through which the mandates of the will pass to the muscles grow more accessible and open by use; and less and less effort of volition becomes necessary to thread them, every time that effort is made.

In the early periods of life the will is exercised in tutoring its corporeal instruments to give prompt and ready obedience to its commands; every day new lessons are acquired, and old ones confirmed; and, having at length a practised body at its beck, it is able to execute numerous and complicated movements with as much precision as those of the most delicate and subtle kind, and all, or any of them, without being itself distracted with the business of their immediate supervision. Like the general of a disciplined army, the will issues mandates of action or controul; but is not cognizant, without a special effort of attention, of anything beyond the general result of the various movements that its orders produce. And the body, that executes them, is constantly performing other movements, of a routine nature, connected with its safety, comforts, or ordinary functions; which, though at first they had demanded the general's attention, and might again attract it, yet, having been learnt by drilling, are now executed without his anxiety or even co-operation. They are the working of a practised organization. Thus many particular movements are included in general ones, without the will having the smallest immediate share in their production. The countenance takes its expression from the prevailing action of its muscles, often in spite of our efforts to the contrary; and, in general, the attitude and bearing wear a corresponding character. And thus several general movements, which naturally (or by an act of the untutored will) are impossible because incompatible, are rendered capable of being simultaneously performed.

The following works may be consulted in reference to Muscle and Muscular Action:—Prochaska, de carne musculari; 1778: Fontana, sur le venin de la vipère; 1781: John Hunter's Croonian Lectures, works by Palmer, vol. iv.; Blane, on Muscular Motion, in his select dissertations; the various works on General Anatomy quoted in former chapters; Barclay on Muscular Motion; Mayo's Physiology; Müller's Physiology, by Bayly; the Articles Muscle and Muscular Action, in the Cyclop. Anat. and Phys. For greater details on the Motions and Attitudes of the body than would be consistent with the plan of this work, we refer to the Article Motion in the Cyclop. Anat. and Phys.; and to Weber's Mechanik der menschlichen Gehwerkzeuge.

CHAPTER VIII.

INNERVATION.—EXAMPLES OF NERVOUS ACTIONS.—NERVOUS MATTER, ITS CHEMICAL AND ANATOMICAL ANALYSIS.—THE FIBROUS AND VESICULAR NERVOUS MATTER.—THE NERVOUS SYSTEM.—THE NERVES, CEREBRO-SPINAL AND SYMPATHETIC.—THE NERVOUS CENTRES.—NERVES AND NERVOUS CENTRES IN INVERTEBRATA.—DEVELOPMENT AND REPRODUCTION OF NERVES.

The function of innervation is effected through the medium of the nervous system, which, ramified throughout the body, and connected with and passing between its various organs, serves them as a bond of union with each other, as well as with the sentient principle of the animal. The mind of man influences his corporeal organs through the instrumentality of this system, as when volition or emotion excites them to action; and, on the other hand, certain changes in the organs or textures of the body may affect the mind through the same channel, as when impressions made upon them excite mental perceptions. In this way the nervous system becomes the main agent of what has been called the life of relation; for without some channel for the transmission of the mandates of the will to the organs of motion, or some provision for the reception of those impressions which external objects are capable of exciting, the mind, thus completely isolated, could hold no communion with the external world.

The nervous system, however, can act independently of mental influence. A material or physical change in the nervous substance, unconnected with any affection of the mind, is capable of exciting the action of nerves, and consequently of those organs which are subject to their influence. Some kind of molecular change in the nervous matter is all that is at any time required for the development of its peculiar power; and it is as easy to conceive that this alteration may result from some organic cause, as from mental influence. Of this kind, no doubt, are all those nervous actions with which are associated the functions of the life of the individual, or, in the language of Bichat, of organic life; an essential character of which is, that they are completely removed from the influence of the will.

In every ordinary voluntary action, the first step is a mental change, in which consists the act of volition. The mind is perfectly able to induce this change in itself, without any reference to the body; but if it direct its influence upon certain muscles, the contraction of those muscles immediately ensues, in a combined and regular manner, so as to produce the predetermined voluntary action. But the influence of the mind cannot be brought to bear upon the muscles, save through the intervention of the nerves, as is amply proved by the destruction of certain voluntary movements, which is consequent upon the destruction of certain nerves.

Again, in all cases of common or of special sensation, that state of the mind, in which the sensation consists, is induced by an impression made upon certain bodily organs, and conveyed to the mind through the instrumentality of the nerves. For there is abundant evidence to prove, that, while the mind is of itself capable of entering that state, it cannot do so in obedience to bodily change, if certain nerves be destroyed or impaired; that, in short, the nerves are the only corporeal channel through which sensations can be excited. If the skin be forcibly irritated or compressed, instantly pain is felt; but, were the nerves of the skin destroyed, no degree of irritation or pressure would make the mind cognizant of the injury. Light is admitted to the eye, and forthwith a corresponding affection of the mind ensues; but, for the production of this, the integrity of the optic nerve is a necessary condition.

In these examples of nervous action, it will be observed that, in the former instance, mental change produces bodily action; and, in the latter, an impression upon some part of the body precedes and gives rise to an affection of the mind. In both cases nervous power is called forth: in the one, it acts in the direction from mind to body; in the other, from body to mind. In both cases, destruction of the nervous matter would prevent the development of the force. The muscles may be sound, and the will may be vigorous; but without perfect nerves the latter cannot impart its mandates to the former. Or the eye may be perfect in all its optical adjustments, and the mental sensibilities keen and quick; and yet, if the optic nerve be diseased, the light which falls upon the retina produces no impression upon the mind.

"Of the nature of the connexion of this great sensorial organ" (the nervous system), says Dr. Brown, "with the sentient mind, we never shall be able to understand more than is involved in the simple fact, that a certain affection of the nervous system precedes immediately a certain affection of the mind. But though we are accustomed to regard this species of succession of bodily and mental changes as peculiarly inexplicable, from the very different nature of the substances which are reciprocally affected, it is truly not more so than any other case of succession of events, where the phenomena occur in substances that are not different in their properties, but analogous, or even absolutely similar; since, in no one iustance of this kind, can we perceive more than the uniform order of the succession itself; and of changes, the successions of which are all absolutely inexplicable, none can be said to be more or less so than another. That a peculiar state of the mere particles of the brain should be followed by a change of state of the sentient mind, is truly wonderful; but, if we consider it strictly, we shall find it to be by no means more wonderful than that the arrival of the moon at a certain point of the heavens should render the state of a body on the surface of our earth different from what it otherwise would naturally be; or that the state of every particle of our globe, in its relative tendencies of gravitation, should be instantly changed, as it unquestionably would be, by the destruction of the most distant satellite of the most distant planet of our system, or, probably too, by the destruction even of one of those remotest of stars which are illuminating their own system of planets, so far in the depth of infinity that their light—to borrow a well-known illustration of sidereal distance—may never yet have reached our earth since the moment at which they darted forth their first beams on the creation of the universe. We believe, indeed, with as much confidence, that one event will uniformly have for its consequent another event, which we have observed to follow it, as we believe the simple fact, that it has preceded it in the particular case observed. But the knowledge of the present sequence, as a mere fact to be remembered, and the expectation of future similar sequences, as the result of an original law of our belief, are precisely of the same kind, whether the sequence of changes be in mind or in matter, singly, or reciprocally in both." *

It is not merely through voluntary effort that the mind can excite the action of nerves. The involuntary, and often uncontrollable, influence of emotion is likewise able to give rise to certain movements, and even to produce certain sensations, through the nerves. How quickly the expression of the countenance changes under the varying phases of mental emotion; and how faithfully does it naturally pourtray the working of the mind within! And

* Brown, Philosophy of the Human Mind. Lect. xix.

fear, joy, disgust, horror, are each accompanied with sensations so peculiar, as to leave an indelible impression on the minds of those who have once experienced them.

There are many actions of the living frame, however, in which the play of the nervous system is unconnected with mental change, which are therefore wholly physical, in origin, as well as in nature. The movement of the œsophagus in propelling food onwards to the stomach is dependent mainly, if not solely, upon the physical stimulus of the food acting upon the nerves of the organ, which in their turn provoke its muscular fibres to contract. The slightest touch, even of a feather, to the mucous membrane of the fauces causes the muscles of deglutition to contract forcibly, as in the act of swallowing; nor can the will controul or prevent their action. When the edge of the eyelid is touched, the orbicular muscle contracts forcibly, and in immediate response to the stimulus applied. When light is suddenly admitted to the eye, the pupil may be observed to contract, to a degree proportionate to the intensity of the stimulus. Of this action of the iris the individual is quite unconscious, although perfectly sensible of the admission of light to the eye: nor can he, by any direct influence of volition, modify or oppose it.

We remark, in reference to these actions, that the mind has no share in their production. In some of them, indeed, it is conscious of the application of the stimulus, as well as of the muscular act which follows. But no effort of the will, however great, could interrupt the uniform and natural sequence of the phenomena. And it is well known to medical men that actions of this kind may take place in coma, when all mental manifestations are completely in abeyance.

These facts afford abundant evidence of a class of nervous actions, which in respect of their exciting cause, as well as in their intrinsic nature, are independent of mental influence, and which ought on this account to be distinguished from those of volition, sensation, and emotion. Their mechanism is more complex than that of the mental nervous actions; for, while in the latter the change in the nerves is propagated in only one direction, in the former it passes first to some central part of the nervous system, and thence it travels in an opposite course to the motor organs. Hence two nerves are necessary for such actions; the one as an excitor, the other as a motor nerve; and, on this account, Dr. Marshall Hall has distinguished these actions by the name of *excito-motory*.

That a physical change may excite nervous action quite independently of mental influence, is further proved by instances of convulsive movements, more or less violent, which are produced by a morbid irritation of the brain or spinal cord.

The peculiar animal matter, through the agency of which all these phenomena take place, *the nervous matter*, is found in two forms, the vesicular and the fibrous. The *vesicular* nervous matter is gray or cineritious in colour, and granular in texture; it contains nucleated nerve-vesicles, and is largely supplied with blood; it is more immediately associated with the mind, and is the seat in which originates the force manifested in nervous actions. The *fibrous* nervous matter, on the other hand, is in most situations white, and composed of tubular fibres, though in some parts it is gray, and consists of solid fibres: it is less vascular than the other, and is simply the propagator of impressions made upon it.

When these two kinds of nervous matter are united together in a mass of variable shape or size, the body so formed is called a *nervous centre*, and the threads of fibrous matter which pass to or from it are called *nerves*. The latter are *internuncial* in their office: they establish a communication between the nervous centres and the various parts of the body, and *vice versâ*; they conduct the impulses of the centres to the periphery, and communicate the impressions made upon the peripheral nervous ramifications to the centres. The centres are the great sources of nervous power, the laboratories in which the nervous force is generated: the mind is more immediately connected with one of them, the brain; which, on that account, possesses greater physical development, and acquires pre-eminence over the others. The smaller nervous centres are called *ganglions*; the larger ones are the *brain* and *spinal cord*. All of these are found in the human subject, and in the vertebrate animals. In the invertebrate classes, the centres are ganglia variously disposed, according to the shape and actions of the animals.

The brain and spinal cord, and the system of nerves connected with them, constitute the *cerebro-spinal* portion of the nervous system, which Bichat distinguished as the nervous system of *animal life*. The nerves of the senses, and those of volition and common sensation, are connected with it, as well as those which are concerned in many of those purely physical nervous actions with which the mind has no connexion. There are very numerous ganglions connected with this system which are conveniently comprehended under the same title. These are, the ganglions on the posterior roots of the spinal nerves, the ganglion of the fifth pair, those of the glosso-pharyngeal and of the vagus.

The remainder of the nervous system is made up entirely of ganglions, with their connecting cords and nerves, which ramify in a plexiform manner among various internal viscera, and upon the coats of blood-vessels. In the higher vertebrate animals, it is disposed as a chain of ganglia on each side of the vertebral column, and at the base of the skull near the foramina through which the spinal and encephalic nerves pass out; and at all these situations it forms a very intimate connexion with the brain and spinal cord. This portion of the nervous system possesses many peculiarities, both in its composition, in its arrangement, and in its connexion with the organs among which its nerves ramify, which, at least, entitle it to be considered apart from the cerebro-spinal system. How far it can be regarded as independent of that system, is a question which must be reserved for future examination. This is the *sympathetic* or *ganglionic system*, formerly known and described as the *great intercostal nerve,* and by Bichat as *the nervous system of organic life:* it has also been called *the visceral nerve.* All these titles are liable to objection, inasmuch as each involves to a greater or less extent some theory of the uses or actions of these nerves; but the two first mentioned are preferable, as those which are best known, and most confirmed by use.

The nervous system, then, in man and the vertebrate series, consists of the brain, spinal cord, and the nerves associated therewith, the *cerebro-spinal system;* and that double chain of ganglia, with their nerves, situate along the spinal column, the *sympathetic* or *ganglionic system.* Among the invertebrata, although the arrangement of the nervous system differs very materially from that in the vertebrata, an analogous subdivision of it may be made in a large proportion of those classes, the anatomy of which has been satisfactorily made out.

Physical and Chemical Properties of the Nervovs Matter.— The nervous matter of both kinds is a soft, unctuous substance, easily disturbed by slight mechanical force. Were it not associated with other tissues, and supported to a certain extent, by the blood-vessels which ramify among its elements, its physical tenacity would be very feeble.

Its great softness is due, in part, to the admixture of a large quantity of water with it, which constitutes three-fourths, or four-fifths, and, in many instances, seven-eighths, of its weight. According to Vauquelin, whose analysis was made in 1812, the brain is an emulsive mixture of albumen, fatty matter, and water: the last holding in solution certain saline and other ingredients common to the brain with other parts of the body. By solution in boiling alcohol, Vauquelin was enabled to resolve the fatty matter into elaine and stearine (margarine?). The following table gives the result of his analysis:

Albumen			7·00
Cerebral fat	Stearine	4·53	5·23
	Elaine	0·70	
Phosphorus			1·50
Osmazome			1·12
Acids, Salts, Sulphur			5·15
Water			80·00
			100·00

Vauquelin remarked that the medulla oblongata, and medulla spinalis, have the same composition as the brain, but contain a much larger proportion of cerebral fat, with less albumen, osmazome, and water.

These results are confirmed, in the main, by the analysis of Fremy, which was published in the Annales de Chimie for 1841. M. Fremy states, that the three principal constituents previously detected by Vauquelin, exist in the following proportions in one hundred parts; seven parts of albumen, five parts of fatty matter, and eighty parts of water.

From the fatty matter of the brain M. Fremy extracts various secondary organic compounds; namely, 1. Cerebric acid; a white substance in the form of crystalline grains, abounding in carbon, and containing a minute proportion of phosphorus. 2. Cholesterine, the same as that which is obtained from bile. In preparations of the brain preserved in spirits, a substance of crystalline character resembling cholesterine is apt to form round the piece. 3. Oleophosphoric acid; a peculiar fatty acid, containing from 1·9 to 2 per cent. of phosphorus in the condition of phosphoric acid. Fremy regards it as analogous to the compound of sulphuric acid and elaine, or sulph-oleic acid. 4. Traces of elaine, margarine, and fatty acids. These principles do not always exist in an insolated state; for the cerebric acid is often combined with soda, or phosphate of lime, and the oleophosphoric acid is commonly found in union with soda.

The quantity of phosphorus which may be found in the nervous matter varies considerably at different periods of life, and is very small in idiotcy. According to L'Heritier's analyses, the *minimum* of this element is found in infancy, in old age, and in idiotcy; and the *maximum* of water exists in the infant. The following is a table of his comparative analyses:—

	Infants.	Youth.	Adults.	Old Men.	Idiots.
Albumen	7·00	10·20	9·40	8·65	8·40
Cerebral fat	3·45	5·30	6·10	4·32	5·00
Phosphorus	0·80	1·65	1·80	1·00	0·85
Osmazome and Salts	5·96	8·59	10·19	12·18	14·82
Water	82·79	74·26	72·51	73·85	70·93
	100·00	100·00	100·00	100·00	100·00

A careful comparative analysis of the vesicular and fibrous matter is as yet a desideratum. We are ignorant of the nature of the colouring material of the former. John states that the vesicular substance is deficient in white fatty matter, and that its albumen is less tenacious than that of the fibrous substance.

Of the Fibrous Nervous Matter.—Of the two kinds of nervous matter, the fibrous is that which is most extensively diffused throughout the body. It not only forms a large portion of the nervous centres, either alone or mixed with vesicular matter, but it is the principal constituent of the infinite multitude of nerves which connect them with the various tissues and organs.

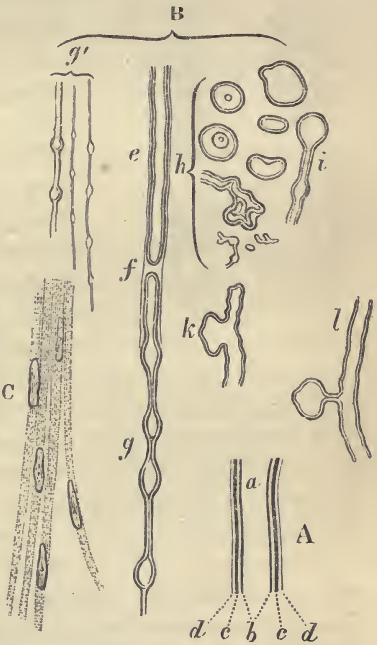
The structure of the fibrous matter should be examined in a piece of nerve, and in a thin section from the white part of a nervous centre, as the brain or spinal cord. These should be torn with needles, so as to separate and isolate as much as possible the elementary parts, and to remove, as far as may be practicable, extraneous tissues.

The fibrous nervous matter, wherever it is found, consists of fibres which have a definite arrangement. Two kinds of primitive fibre are present in the nervous system, and these we shall distinguish as the *tubular* fibre, or the *nerve-tube,* and the *gelatinous* fibre. The former are infinitely the more numerous; the latter being found chiefly in the sympathetic system.

1. *Of the Tubular Fibre.*—When a nerve-tube is perfectly recent, and unaffected by reagents, it presents, if viewed by reflected light, a beautiful pearly lustre, and appears to be quite homogeneous. But if viewed by transmitted light, and with a sufficient magnifying power, a more complicated structure becomes visible in all the largest and best marked specimens (fig. 52, A, B, and fig. 53, *a*). Most externally is the *tubular membrane* (A, *d d*), an homogeneous, and probably elastic tissue of extreme delicacy, analogous to the sarcolemma of striped muscle (p. 155), and according to our observation, not presenting any such distinct, longitudinal, or oblique fibres in its composition as have been described by some writers.

Within the edge of the tubular membrane, on each side, are seen two thicker and darker lines (A, *c*, *c*, *b*), which appear to mark the outer and inner limits of an inner layer of different composition and refracting power, and which is generally known as the *white substance of Schwann.* This forms a tube within the tubular membrane. Within the white substance of Schwann is a transparent material, occupying the axis of the nerve-tube (A, *a*). This has been called by Remak the *flattened band;* but a better name for it is that of *axis cylinder,* employed by Rosenthal and Purkinje.

Fig. 52.

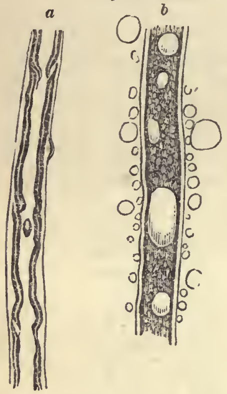


A. Diagram of tubular fibre of a spinal nerve:—*a.* Axis cylinder. *b.* Inner border of white substance. *c, c.* Outer border of white substance. *d, d.* Tubular membrane. B. Tubular fibres; *e,* in a natural state, shewing the parts as in A. *f.* The white substance and axis cylinder interrupted by pressure, while the tubular membrane remains. *g,* The same, with varicosities. *h.* Various appearances of the white substance and axis cylinder forced out of the tubular membrane by pressure. *i.* Broken end of a tubular fibre, with the white substance closed over it. *k.* Lateral bulging of white substance and axis cylinder from pressure. *l.* The same more complete. *g'.* Varicose fibres of various sizes, from the cerebellum. C. Gelatinous fibres from the solar plexus, treated with acetic acid to exhibit their cell-nuclei. B and C magnified 320 diameters.

It is evident, that the whole of the matter contained in the tubular membrane is extremely soft, for it is found to yield under very slight pressure, and may be readily made to pass from one part of the tube to another. When pressed out (B, *h* to *l*), it is apt to assume more or less the appearance and form of globules, which retain the same characters of outline which they possessed in the nerve-tube: that is, they have a transparent interior, bounded by a layer of the white substance of Schwann, marked by its double contour. It would appear that the latter structure is particularly apt to form a coating or film over the central material, and thus to isolate it from surrounding tissues. This tendency may be understood by a reference to fig. 52, *h* to *l*.

When the nerve-tube is placed in æther, the white substance is in part immediately dissolved, and a number of oil-like globules appear both within and without the tubular membrane (fig. 53, *b*). Probably its margarine is dissolved, and the elaine set free in the form of oil-globules. The interior of the tube is also rendered decidely granular. In water the white substance of Schwann remains undissolved, while the interior of the fibre is frequently, though not always, rendered granular.

Fig. 53.



Nerve-tubes of the common eel.—*a.* In *water.* The delicate line on its exterior indicates the tubular membrane. The dark, double edged inner one is the white substance of Schwann, slightly wrinkled. *b.* The same in *æther.* Several oil-globules have coalesced in the interior, and others have accumulated around the exterior of the tube. The white substance has in part disappeared.—Magnified 300 diamêters.

The tubular membrane presents the same general characters wherever it is met with. But the white substance of Schwann exhibits much variety as regards its thickness in different parts of the nervous system. In the nerves it is more developed than in the centres; but even in the former it differs a good deal as to thickness. We find it most developed in the ordinary spinal nerves; in those of pure sense it exists in small quantity. Both these elements of the tubular fibre evidently afford mechanical protection to the substance which forms its axis; but doubtless one or both of them may have a further physiological office, in insulating the axis, and keeping it distinct from any interference with constituents of neighbouring fibres. The chemical composition of the white substance, being obviously different from that of the axis, sufficiently denotes a difference of function in these two portions of the nerve-tube. The axis cylinder of the nerve-tube, though in general soft and pulpy, is in some instances of firm texture, and when broken projects beyond the white substance (fig. 56, *c*). It then occasionally exhibits a well marked fibrous character, and may even split into filaments.

When the tubes are quite fresh, and have been but little disturbed by manipulation, their form is that of a perfect cylinder. Pressure, or separation, is apt to alter their shape by disturbing the position of the contained pulp, pushing more than is natural into some parts of the tube, and consequently diminishing the bulk of the contents in the adjacent parts; so that the latter collapse, whilst the former become distended, enlarged, and even varicose (fig. 52, B). Nerve-tubes, that have been thus affected, sometimes present merely a slight waviness of one or both margins, but more frequently a series of distinct swellings or varicosities separated by constricted portions. These swellings are found at very irregular distances from each other, and vary extremely in shape and size. They are much more apt to form upon some nerve-tubes than upon others; and this is apparently owing to a feebleness of the tubular membrane, and perhaps, also, to a less degree of consistence of the contained nervous pulp. In the nerves of special sensation the tubes are very delicate in structure, and very apt to exhibit this change; and in the fibres of the brain and spinal cord the same tendency is observable. It was formerly supposed by Ehrenberg, that these varicosities were natural, and existed during life; and that they afforded a valuable morphological character of the nerves of pure sense, and of the cerebro-spinal centre. Many circumstances, however, oppose this view; thus, the irregularies in the shape, size, and number of the varicosities appear very unlike a natural disposition: in a piece of the brain or spinal cord, which has not been much pressed or torn, the nerve-tubes often exhibit a cylindrical figure, and even in the manipulated specimen the varicose tubes form only a portion. In some nerves, such as those of muscles, the tubes, although not prone to become varicose, may be made so by firm pressure and violence in manipulation; and in the nerve-tubes of young animals, the tissues of which are more tender, and contain more abundant water, this change is particularly apt to take place.

The nerve-tubes, for the most part, lie parallel to each other, always without branching, and, if we except their terminal looping in other textures, without any inosculation. This very interesting and important feature in the anatomy of the nerve-tubes was recognised long ago by Fontana, and has been confirmed by nearly every subsequent observer. It may be seen in the nervous centres, as well as in the nerves themselves. In the latter it may be well demonstrated by examining a piece of nerve on a dark ground as an opaque object. The primitive fibres, viewed in this way, appear as so many transparent tubes, containing an exquisitely delicate, soft, pearly-white material. The tubular fibres vary in diameter from $\frac{1}{1600}$ to even $\frac{1}{10000}$ of an inch; but their average width is from $\frac{1}{2000}$ to $\frac{1}{4000}$ of an inch.

2. *Of the Gelatinous Nerve-fibre.*—This term is applied by Henle to certain fibres found principally in the sympathetic nerve. They are flattened, soft, and homogeneous in appearance; containing numerous cell-nuclei, some of which are round, others oval; some situated in the centre of the fibre, others adhering to either edge; their longest diameter being generally parallel to the longitudinal axis of the nerve. These nuclei are arranged at nearly equal distances, and frequently exhibit distinct nucleoli (fig. 52, c). Sometimes these fibres show a disposition to split into very delicate

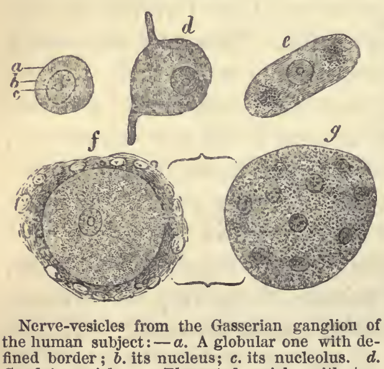
fibrillæ. Acetic acid dissolves the fibre, leaving the nuclei unchanged. These fibres, containing nothing analogous to the white substance of Schwann, are devoid of that whiteness which characterises the tubular fibre; and it would seem that the gray colour of certain nerves depends chiefly upon the presence of a large proportion of the gelatinous fibres. Hence they are sometimes called *gray fibres*.

The mode of connexion of the gelatinous fibres with the elements of the nervous centres is, as yet, quite unknown. They are found, in considerable numbers, in what are called the roots of the sympathetic, or the communications of that nerve with the spinal nerves: it has been supposed by Valentin that they are continuous with certain elements of the vesicular nervous matter.

These fibres are smaller, in general, than the tubular fibres; their diameter ranges between the $\frac{1}{6000}$ and the $\frac{1}{4000}$ of an inch. They resemble very much the fibres of unstriped muscle.

Of the Vesicular Nervous Matter.—This is distinguished by its dark reddish gray colour, and soft consistence: it is found in the nervous centres, but never in nerves, properly so-called, and it is always supplied by a considerable plexus of blood-vessels.

Fig. 54.



Nerve-vesicles from the Gasserian ganglion of the human subject:—*a*. A globular one with defined border; *b*. its nucleus; *c*. its nucleolus. *d*. Caudate vesicle. *e*. Elongated vesicle, with two groups of pigment particles. *f*. Vesicle surrounded by its sheath, or capsule, of nucleated particles. *g*. The same, the sheath only being in focus.—Magnified 300 diameters.

The essential elements of the gray nervous matter are *vesicles* or cells, containing nuclei and nucleoli. They have been also called *nerve* or *ganglion globules*. The wall of each vesicle consists of an exceedingly delicate membrane, containing a soft but tenacious finely granular mass. The *nucleus* of the cell is generally eccentric, much smaller than the containing vesicle, and adherent to some part of its interior. Its structure is apparently the same as that of the outer vesicle. The *nucleolus* is a minute, remarkably clear, and brilliant body, also vesicular, inclosed within the nucleus. It forms a most characteristic and often conspicuous part of the nerve-vesicle.

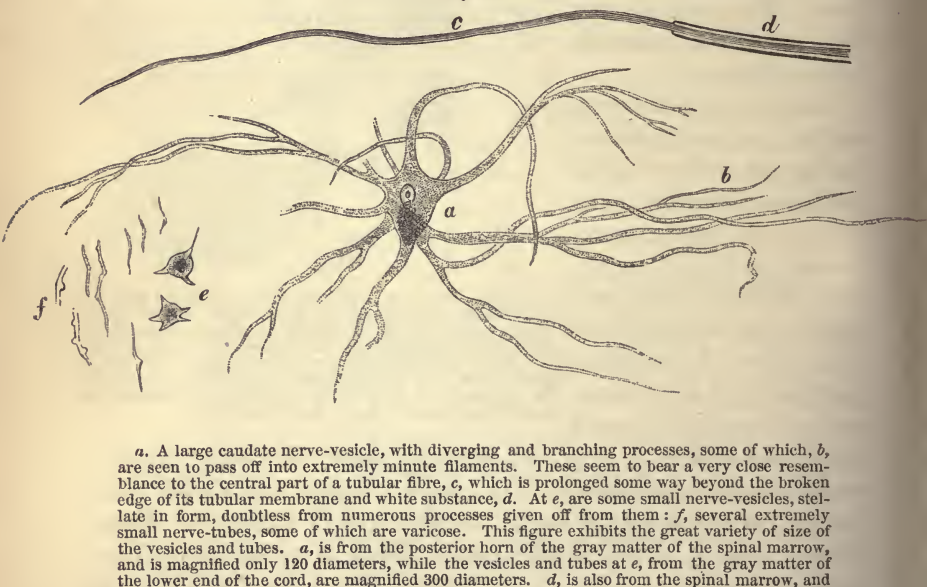
The ordinary or prevailing form of these elements is that of a globular vesicle. So soft and compressible are they, however, that a good deal of diversity of shape is manifest in them, by reason of the compression they suffer as they lie packed together *in situ.* Hence some are spherical, others ovoidal, or ellipsoidal. In some vesicles we find, external to the nucleus, particles of a coarser kind, which are accumulated in a mass, frequently of a semilunar form. These are pigment granules; their presence gives a dark colour to a portion of the vesicle. Sometimes we find two groups of pigment granules in one vesicle. They are usually of a reddish or yellowish brown colour.

Fig. 55.

Ganglion globules, with their processes, nuclei, and nucleoli; —*a. a.* From the deeper part of the gray matter of the convolutions of the cerebellum. The larger processes are directed towards the surface of the organ. *b.* Another, from the cerebellum. *c. d.* Others from the post. horn of gray matter of the dorsal region of the cord. These contain pigment, which surrounds the nucleus in *c.* In all these specimens the processes are more or less broken.—Magnified 200 diameters.

Another form of nerve-vesicle is characterized by one or more tail-like processes extended from it, and to such nerve-vesicles we may apply the term *caudate.* They possess the nucleus and nucleolus, as in the more simple form; and contain one or more masses of pigment which are often of very considerable size. Both the vesicles and their caudate processes vary greatly in size and shape. The largest nerve-vesicles are found among those of this kind. Sometimes there is but a single process from a vesicle; or there may be two, proceeding from opposite sides; or there may be several, extending in various directions. There is great difference in the shape of these caudate vesicles, as may be observed in figs. 55 and 56, where different varieties of them have been represented. In point of structure, the caudate processes are exceedingly delicate, and finely granular, like the interior of the vesicle, with which they distinctly seem to be continuous. Such is the delicacy of these processes, that they readily break off; in general, very close to the vesicle. Sometimes, however, one or more of them may be traced to a considerable distance, and will be found to divide into two or into three branches, which undergo a further subdivision, and give off some extremely fine transparent fibres (fig. 56, *b*), the connexion of which with the other elements of the nervous tissue has yet to be ascertained. It is most probable, however, that they either serve to connect distant vesicles, or else that they become continuous with the axis cylinders of the tubular fibres. In the cerebro-spinal centre, we have found the tissue in the vicinity of the caudate vesicles freely traversed in all directions by numerous very delicate filaments, which seem to be the ramifications of the caudate processes. These often exhibit considerable tenacity and elasticity. The situations from which we may obtain such caudate vesicles as are best suited for examination, are the *locus niger* in the crus cerebri, and the gray matter of the cerebellum and spinal cord.

Fig. 56.

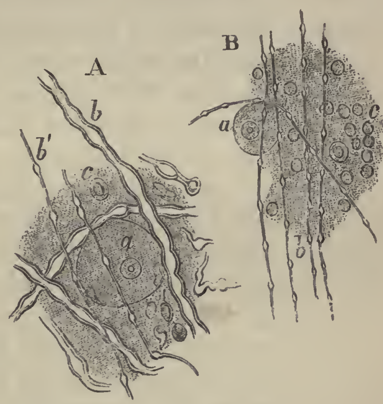


a. A large caudate nerve-vesicle, with diverging and branching processes, some of which, *b*, are seen to pass off into extremely minute filaments. These seem to bear a very close resemblance to the central part of a tubular fibre, *c*, which is prolonged some way beyond the broken edge of its tubular membrane and white substance, *d*. At *e*, are some small nerve-vesicles, stellate in form, doubtless from numerous processes given off from them : *f*, several extremely small nerve-tubes, some of which are varicose. This figure exhibits the great variety of size of the vesicles and tubes. *a*, is from the posterior horn of the gray matter of the spinal marrow, and is magnified only 120 diameters, while the vesicles and tubes at *e*, from the gray matter of the lower end of the cord, are magnified 300 diameters. *d*, is also from the spinal marrow, and is magnified 200 diameters.

The nerve-vesicles do not lie in immediate contact with each other. They are either imbedded in a soft, granular matrix, as in the brain, or enveloped in a capsule of nucleated cells, as in the ganglia (fig. 54, *f*, *g*). The intimate connexion of this granular sheath to the vesicle, and to its processes when they exist, increases greatly the difficulty of examining them. It is not easy to detach them from this investment. This is generally effected by accident more than by skill in manipulation, and it is along the broken margin of the piece under examination that we shall succeed in detecting the most perfect vesicles.

In most situations where vesicular matter is found in the nervous centres, tubular fibres of small though variable size mingle with its elements in greater or less number, and in some places both varieties of fibre are found (figs. 57 & 58). To determine the precise connexion which these respective elementary parts form with each other is a problem of the deepest interest. No more, however, can be said respecting it at present, than that the relation of nerve-fibres to nerve-vesicles in the centres is most intimate, and that the latter are rarely met with without one or more of the former in immediate connexion with them.

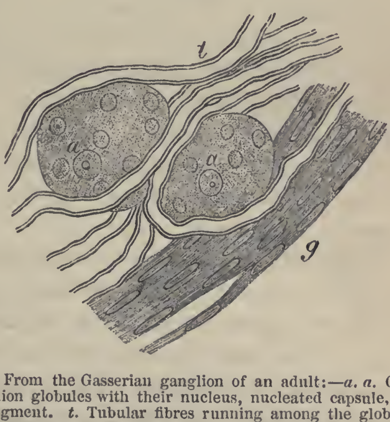
Fig. 57.



A. Blending of the vesicular and fibrous nervous matter in the dentate body of the cerebellum:—*a.* Ganglion globule, with its nucleus and nucleolus. *b.* Nerve-tube, slightly varicose, in close contact with the ganglion globule. *b'.* Smaller nerve-tubes. These parts all lie in a finely granular matrix interspersed with nuclei, *c.* B. Vesicular and fibrous matter of the laminæ of the cerebellum. *a.* Ganglion globule. *b.* Very minute nerve-tubes traversing a finely granular matrix, in which are numerous rounded nuclei, *c.*

Having premised this general account of the anatomical elements of the two kinds of nervous matter, we may now consider separately the two leading subdivisions of the nervous system; namely, the nerves and the centres.

Fig. 58.



From the Gasserian ganglion of an adult:—*a. a.* Ganglion globules with their nucleus, nucleated capsule, and pigment. *t.* Tubular fibres running among the globules in contact with their capsule. *g.* Gelatinous fibres also in contact with the ganglion globules.—Magnified 320 diameters.

Of Nerves.—A bundle of nerve-fibres, surrounded and connected by areolar tissue, constitutes a nerve.

The nerves of the cerebro-spinal system differ in several important particulars from those of the sympathetic, and they should, therefore, be examined separately.

Of the Cerebro-spinal Nerves.—The areolar tissue which invests the nerve-fibres is called *the neurilemma.* It is analogous to the sheath of the same membrane which surrounds the elementary fibre of striped muscle. From its deep surface thin layers of areolar tissue pass, forming so many partitions between the smaller bundles, or the individual fibres, of which the nervous trunk is composed. The office of this structure is evidently to give protection to the delicate nerve-tubes, and to support the plexus of minute capillary vessels from which they derive their nutriment.

The neurilemma is composed of fibres of white fibrous tissue, and presents to the naked eye the silvery aspect of that texture. Some persistent cell-nuclei are scattered throughout it. That portion of it which forms the partition between the fibres contains a little yellow fibrous tissue of the finest description.

The *blood-vessels* are distributed upon the external investing sheath, and upon the septa. They are disposed similarly to those of muscles, and run parallel to the fibres of the nerve. The capillaries are among the smallest in the body: they form oblong meshes of considerable length, completed at long intervals by vessels which cross the fibres of the nerve more or less transversely. These blood-vessels are generally derived from neighbouring arterial branches; sometimes a special vessel accompanies a nervous trunk, and even perforates it, passing along its axis, as in the great sciatic and the optic nerves.

The composition of a cerebro-spinal nerve may be shown by removing the neurilemma, and separating the fibres by needles. These fibres are chiefly of the tubular kind. In diameter they vary considerably, but do not exceed the $\frac{1}{1500}$ of an inch in man and the mammalia. They lie within the sheath in simple juxtaposition, and parallel to each other; excepting where a branch is about to separate, when a bundle of nerve-tubes gradually deviates from its previous course, and forms a very acute angle with the trunk, still, however, preserving the parallelism of its constituent fibres.

Nerves are said to *arise* or have their *origin* in the nervous centre to which they are on the one hand attached, and to *terminate* or *be distributed* among the elements of the various textures on the other hand. It is best to continue the use of so definite and simple a meaning to these terms. Attempts to alter their signification in accordance with opinions of the functions of the constituent fibres can at present do little but confuse descriptions. We call a nerve *cerebral* or *encephalic*, if it be connected at its origin with some part of the nervous mass within the cranium; and *spinal*, if its apparent origin be from the spinal cord.

Origin.—The fibres of nerves may be traced into the nervous centres, the white or fibrous part of which they contribute to form. As they enter the centre, the fibres diverge slightly either singly or in separate bundles, and pass on to form a connexion with vesicular matter, in the immediate vicinity of the point of immergence or at a more remote situation. How the fibres comport themselves with respect to the elements of the vesicular matter is not exactly known. It is certain, however, that nerve-tubes frequently adhere to the sheaths of nerve-vesicles, and that many of them pass between the nerve-vesicles, probably to form a connexion with more distant ones. This may be well seen in the vesicular matter of any of the centres. It is very distinct in the ganglions, and also sufficiently manifest in the spinal cord or brain. In the last-named centres some of the tubes which are found in the vesicular matter are reduced to an extremely minute size (figs. 56, *f*; 57, A, *b*′ and B, *b*), and exhibit small varicosities, sometimes at very regular distances from each other.

Valentin describes a looped and plexiform arrangement of the fibres in the vesicular matter of the centres. Hitherto, such an arrangement has eluded our observation so completely, that, but for the high authority on which this statement rests, we should not have deemed it necessary to allude to it. The only confirmation of this view with which we have met is derived from a highly interesting dissection, by Mr. Lonsdale of Edinburgh, of a monstrosity, in which the spinal cord, medulla oblongata, and cerebellum were absent, but the hemispheres of the brain were present. Several of the encephalic and spinal nerves hung as "loose threads" in the cavity of the cranium or spine. On examining the free or central extremities of these nerves, their constituent fibres were found to form distinct loops, convex towards the cranial or spinal cavity. These loops were imbedded in granular matter, supposed to be vesicular matter in an early stage of formation. Similar loops were observed by the same anatomist in the cranial nerves of an anencephalous fœtus which had been preserved in spirits.*

Branching.—As a nerve passes from centre to periphery, it breaks up into a number of small bundles, which form so many branches destined for the organs or tissues among which they are placed. These branches generally separate from the parent trunk at an acute angle, and soon plunge into the muscles or other parts to which they tend, dividing and subdividing among them. Some

* Dr. Lonsdale's case of Monstrosity. Ed. Med. and Surg. Journ., No. 157.

exceptions to this rule, however, are occasionally met with, in which the branch forms a right or an obtuse angle with the trunk.

Before a branch separates, the parent nerve seems wider for some distance above the point of visible separation. This is owing to a divergence of the fibres within the trunk before they actually leave it, and not to any increase in the number of the nervous elements. A good example may be seen in the auricular nerve of the neck, as it winds upwards over the sterno-mastoid muscle.

Anastomosis.—In their branchings nerves subdivide, not only to pass immediately to their distribution in muscles or other parts, but also to form a connexion, by some of their filaments, with other nerves, and to follow the course of the latter, whether to the periphery, or back again to the centre, instead of passing to the destination of the primary trunk. By these means nervous filaments connected with very different parts of the brain and spinal cord become bound together in the same neurilemma, and a nerve is formed compounded of nerve-tubes possessing different functions. The *anastomosis* of nerves thus formed differs from the more correctly-named anastomosis of blood-vessels; for in the latter case the canals of the anastomosing vessels communicate, and their contents are mingled; but in the former the nerve-tubes simply lie in juxtaposition, without any coalescence of their walls, or any admixture of the material contained within them.

The simplest kind of anastomosis is that which occurs in almost every spinal nerve. The anterior and the posterior roots of these nerves, emerging from different parts of the spinal cord, and possessing, as is now proved, very different endowments, are united after passing through the dura mater, and are bound together as one nerve; the respective tubules being so completely intermixed that the ramifications, which pass off in the subsequent course of the nerve, for the most part contain tubules from both roots, and therefore possess the functions of both.

Fig. 59.

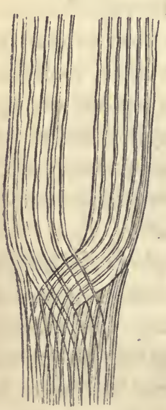


Diagram to shew the decussation of the fibres within the trunk of a nerve.—After Valentin.

And even in a nervous trunk, thus formed, there is an interchange of place between the component filaments, so that those which were at first on the surface of the nerve pass into its centre, and are replaced by others which had been deep-seated; a decussation of the fibres occurring as they change places (fig. 59). Hence it is often difficult to follow a bundle for any distance in a nervous trunk.

According to Kronenberg, this kind of interchange is more frequent in some nerves than in others; and it is stated by this author that in the external cutaneous nerve of the arm he found some bundles, which passed through a distance of six inches without uniting with neighbouring ones.

By another form of anastomosis nervous loops or arches are formed, the convexities of which are directed towards the periphery, and give off filaments to the neighbouring parts. The well-known anastomosis between the ninth or hypoglossal nerve, and the cervical plexus, in front of the carotid artery, may be quoted as a good example. Certain fibres, which come from the medulla oblongata as part of the ninth nerve, leave that nerve as it crosses over the carotid artery, pass down in front of the artery, and apply themselves to a descending branch of the cervical plexus, forming in front of the carotid artery and jugular vein an arch with the concavity directed upwards, several nerves passing from the convexity to neighbouring muscles. Some of the filaments which are given off from this arch, are derived from the ninth nerve, and others from the cervical plexus; whilst others seem to form a complete arch, and to be equally connected with both nerves; and, if we trace these latter fibres from the ninth nerve, we find them passing upwards and backwards into the descending branch of the cervical plexus, and so returning to the spinal cord. The nervous loop, thus formed, must evidently establish a communication between the cervical region of the spinal cord and that portion of the medulla oblongata whence the ninth nerve appears to derive its origin.

Similar nervous loops, leaving the nervous centre as a constituent of one nerve, and returning to it at some distance in company with a different nerve, are found in various parts of the nervous system. The commissural fibres of the optic tracts may be quoted as an example. These fibres leave the centre by one tract, and return to it by the other. It is probably owing to an anastomosis of this kind, between the posterior and anterior roots of the spinal nerves, that the latter enjoy a slight degree of sensibility. Other instances of a similar kind have been described by Volkmann. In the calf he found an anastomosis between the fourth pair of nerves and the first branch of the fifth pair, forming an arch, from the convexity of which several branches passed off in the peripheral direction. By far the greater part of these, on microscopic examination, appeared to receive their fibres from the fourth; while those fibres of the fifth, which contributed to the formation of the arch, passed centripetally to the brain, bound up in the sheath of the fourth nerve. There is a similar nervous arch formed between the second or third cervical nerve and the accessory nerve. Certain fibres, when traced from the former, appear to pass back to the centre in the sheath of the latter. This anastomosis Volkmann found in the human subject, and in several of the lower animals.*

According to Gerber, similar loops are found in the sheaths of spinal nerves. Certain fibres emerge from and return to the nervous centre, forming a loop with the convexity directed towards the periphery, without connecting themselves with any peripheral organ or texture, or going beyond the nerve-sheath. To these loops this anatomist has given the fanciful title, *nervi nervorum.*

Plexuses.—When several neighbouring nerves freely interchange their fibres, a complicated form of anastomosis is produced, which is called a plexus. Four or five nerves, for example, proceed from the spinal cord, for a certain distance without any communication with each other. A division of each then takes place, and from the conjunction of their neighbouring branches new nerves result, which again subdivide and interchange fibres; and by the free communication which is thus established, a network is sometimes formed, (as in the cervical plexus), in the meshes of which areolar tissue, and sometimes fat, are deposited. Finally, certain nerves emerge from the plexus thus formed, which are composed of fibres derived from several of the original trunks. Examples of this kind of anastomosis are found in connexion with the anterior branches of the spinal nerves in the neck, the axilla, the loins, and the sacral region; and there are also plexuses formed in the course of the fifth nerve, the portio dura of the seventh, the glosso-pharyngeal, and the par vagum.

The fibres, which pass through a plexus, notwithstanding the apparent intricacy of their communication, preserve their individuality. This may be proved by irritating a single nerve before it has broken up in the plexus. Such irritation will produce contraction of certain muscles only; of those, namely, to which the fibres of that nerve are distributed. It is probable that, owing to the frequent change of place which the fibres undergo within the plexus, they are brought into communication with a greater number of muscles than if no such subdivision had taken place. Kronenberg's experiments shewed that the irritation of certain nerves of the plexus before their subdivision caused the contraction of those muscles only which received filaments from them.†

* Müller's Archiv., 1840.

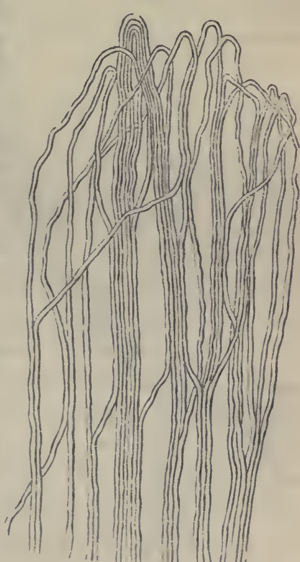
† Plexuum nervorum structura et virtutes. Berol. 1836.

Termination of Nerves.—The connexion which the terminal filaments of nerves form with the proximate constituents of the striped muscle has been already described (p. 168). From that description it will appear that the nervous fibres do not come into immediate communication with the sarcous substance, unless we have recourse to the supposition that some minute elements proceed from those fibres, and penetrate the sarcolemma. Such a supposition has no foundation in anatomy, so far as our present knowledge extends. It is a curious subject of investigation to determine what becomes of the nerve-tubes, which, after the formation of the loops which cross the muscular fibres, take a retrograde course towards the nervous centre. Do they, for instance, return to the spinal cord? and can it be their office to form a second connexion with the vesicular matter of the cerebro-spinal centre, the descending fibre coming from the brain, and the returning one being implanted in the gray matter of the cord?

In the skin the arrangement is plexiform; but this is reducible to loopings, as will be explained in the chapter on Touch.

The arrangement of the primitive fibres in loops has been also seen by Henle on some parts of mucous membrane; in the membrana nictitans of the frog, for example, and in the mucous membrane of the throat in the same animal. A similar disposition has been described and delineated by Valentin in the pulps of the teeth (fig. 60), and we have seen it in the papillæ of the tongue.

Fig. 60.



Terminal nerves on the sac of the second molar tooth of the lower jaw in the sheep, shewing the arrangement in loops. —(After Valentin).

The so-called *nerves* of pure sense, the olfactory, optic, and auditory nerves, may more properly be regarded as portions of the brain itself than as mere nerves, for they possess most of the anatomical characters of nervous centres. The intra-cranial portion of the first is as distinctly compounded of vesicular and fibrous matter as a convolution of the brain. In the peripheral expansion of the optic nerve, the retina, it will be hereafter shown that the vesicular elements of a nervous centre are as unequivocally present as in the olfactory bulb. As regards the auditory nerve, there are also some grounds for the statement that the vesicles of gray matter are deposited at its peripheral expansion in the internal ear.*

Of the Ganglionic or Sympathetic Nerves.—The composition of these nerves is essentially similar to that of the cerebro-spinal nerves. They consist of a series of nerve-fibres bound together by areolar tissue which forms their neurilemma. This sheath is, however, denser than in the cerebro-spinal nerves, so that the nerve-fibres are more difficult of separation, and the fasciculated character is not so obvious. It consists almost entirely of white fibrous tissue longitudinally disposed, which are crossed by some fine circular fibres of yellow tissue, surrounding the nerves at various distances from each other. When a nerve is torn up by needles, and treated by acetic acid, numerous small oval cell-nuclei are seen lying in and among the fibres, with their long axes parallel to the latter.

Fig. 61.

Roots of a dorsal spinal nerve, and its union with sympathetic:—*c*, *c*. Anterior fissure of the spinal cord. *a*. Anterior root. *p*. Posterior root, with its ganglion. *a'*. Anterior branch. *p'*. Posterior branch. *s*. Sympathetic. *e*. Its double junction with the anterior branch of the spinal nerve by a white and a gray filament.

The sympathetic nerves contain the fibres of both kinds, the tubular and the gelatinous, in very variable quantity in different nerves. Thus, the former are numerous in the ramifications of the solar plexus and in the cardiac nerves; and the latter almost exclusively compose one of the fascicles by which the sympathetic communicates with the spinal nerves (fig. 61, *e*): they are also numerous, while the tubular fibres are few, in the sympathetic cord in the neck. In some nerves, the tubular fibres are quite on the surface; and in others, they are enclosed in the axis of the nervous trunk. It is probable that the same change of place between the fibres occurs in these nerves as that which we have noticed in the

* See further on these points the chapters on Smell, Vision, and Hearing.

cerebro-spinal nerves; so that those fibres which at one part of the nerve were superficial, would at another be deep-seated, and *vice versâ*.

The mode of branching of these nerves is essentially the same as that of the cerebro-spinal. But the frequent formation of ganglia in the course of the trunks, and of their ramifications, constitutes a remarkable feature. The branches attach themselves to the exterior of arteries, forming very intricate plexuses, which entwine around them, "hederæ ad modum" (Scarpa). Along these vessels the nerves are conveyed to the tissues; but of the mode in which their filaments connect themselves immediately with those textures we are at present entirely ignorant. The ramifications of the sympathetic seem to be limited to the trunk and head; it has probably no connexion, or at most a very limited one, with the extremities.

The connexion of the sympathetic system with the brain and spinal cord appears to take place through the cerebro-spinal nerves. Certain filaments connect each spinal nerve to some portion of the ganglionic chain which lies on each side of the spinal column. And a similar connexion takes place between ganglia of the cephalic portion of the sympathetic and the encephalic nerves, of which the following may be cited as well-known instances:—The third nerve is connected with the ophthalmic ganglion; the sixth with the superior cervical ganglion; the fifth nerve with the spheno-palatine and otic ganglia. These connecting filaments have been called the roots of the sympathetic; and thus this nerve has been represented as taking an extended origin from numerous points of the cerebro-spinal centre. This is true: but, in dissecting the connexion between the sympathetic and the spinal nerves, we find that, for the most part, two distinct fascicles connect them, one of which is white, being composed of tubular fibres; the other is gray, and consists of gelatinous fibres. The former seem evidently cerebro-spinal fibres, which pass to or from the periphery conjoined with the other elements of the sympathetic: but, in the present state of our knowledge, it is difficult to form a correct idea as to the precise object of the latter bundles, or as to the central connexion which they form, whether with the ganglion on the posterior root of each spinal nerve, or with the spinal cord. That the sympathetic has intimate and extensive connexions with the brain and spinal cord, is abundantly proved, not only by the anatomical statements above detailed, but by the circumstance of which every one is conscious, that pain may be excited in parts supplied from this system of nerves alone, as in the intestines; as well as by the fact that irritation of the spinal cord may produce contraction of muscles which derive their nerves from this source, and that destructive disease of that organ may occasion paralysis of those muscles.

Of the Nervous Centres.—The nervous centres exhibit to us the union of the vesicular and the nervous fibrous matter. Indeed the association of these two forms of nervous substance in a mass of variable shape or size is the main anatomical condition for the formation of a nervous centre. The former is never met with in nerves properly so-called, and when a true nerve has a grayish appearance, we find that it is owing to a paucity of the tubular, and an excess of the gelatinous fibres.

All nervous centres are provided with a proper covering which serves to isolate them from adjacent textures and to protect them, as well as to support their nutrient blood-vessels. In the ganglia this covering is continuous and identical with the neurilemma of the nerves which are connected with them, and it is in every respect of the same structure as the latter membrane.

In the larger centres, the brain and spinal cord, the coverings are of a more complicated kind. They are called *meninges,* membranes. Three of them are enumerated: The *dura mater,* which is external; the *pia mater,* which is in immediate connexion with the nervous matter of the centre; and the *arachnoid membrane,* a serous sac intermediate to the two tunics just mentioned, which is evidently destined to facilitate the movements of these organs within their proper cavities. These will be more particularly described further on.

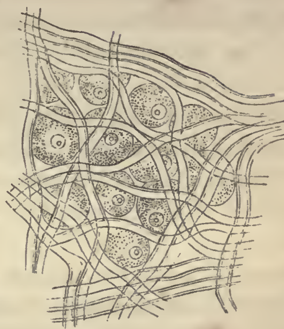
In examining the ganglia, we obtain a good idea of the minute structure of nervous centres in general. A thin slice of one of the larger ganglia, torn up by needles, or a small ganglion from some small animal, serves to shew the disposition of the vesicular and fibrous matter in these bodies.

Fig. 62.

Second abdominal ganglion of the greenfinch, slightly compressed. The course of the nerve-tubes only is represented. *a.* Entering fibres. *b.* Emerging fibres. *i.* Outline of investing tunic, beneath which vesicles exist. —(After Valentin).

A ganglion may be compared to a plexus, with nerve-vesicles deposited in its meshes (figs. 62, 63). In tracing a nerve into a ganglion, its component fibres appear to separate, and to pass through the ganglion in different directions; some maintaining their original course, others diverging from it for a short way and afterwards returning to it, and others taking altogether a new direction and passing out of the ganglion in combination with other fibres, to form an emerging nerve. A certain degree of interlacement of the fibres thus takes place within the ganglion, and in its interstices are lodged the nerve-vesicles enveloped by their proper sheaths. A great number of nerve-fibres may be traced through the ganglion, so that the emerging nerves may be regarded as resulting from a new combination of the fibres that compose the nerves which entered the ganglion. These, however, are possibly not the only constituent fibres of the emerging nerves, for it has yet to be ascertained whether some fibres may not take their rise from the vesicular matter of the ganglion, and it is a not less interesting object of inquiry whether some of the entering fibres may not terminate in it. That the nerve-tubes have an intimate connexion with the elements of the vesicular matter is apparent, from the fact that they lie in close apposition with them, and appear to indent their sheaths of nucleated corpuscles (fig. 57). Sometimes the sheath seems to taper off from the nerve-vesicles, and to become continuous with the nerve-tubes. It is a conjecture by no means devoid of probability, that the processes of the caudate vesicle may, after passing some way, become invested by the tubular membrane and by the white substance of Schwann, and we have seen some appearances to warrant this view (see fig. 56, *c*, *d*). Yet it should be stated, as opposed to this view, that in the gray matter of the cerebellum the caudate vesicles are so placed that their processes pass toward the free surface of the cortical layer, and not into the white matter.

Fig. 63.



A small piece of the otic ganglion of the sheep, slightly compressed; shewing the interlacement of the internal fibres, and the vesicular matter.—(After Valentin).

Besides the tubular fibres, the ganglia contain likewise gelatinous ones, which, however, are more abundant in the sympathetic than in the cerebro-spinal ganglia (fig. 58, *g*). These fibres are, doubtless, continuous with those of the same kind which may exist in the entering or emerging nerves. We may also add, that the vesicular matter does not appear to be confined to the interstices between the fibres, but is likewise found at the surface of the ganglia, lying in immediate contact with their investing tunic.

In the brain and spinal cord, there is a greater separation of the vesicular and fibrous matter than in the ganglia. The former very complicated organ, indeed, consists of various masses which are in all essential points very similar to the ganglia in structure, and doubtless also in function; but its hemispheres are larger masses, of which the interior substance is composed exclusively of fibrous matter, surrounded by a layer of vesicular, which forms a rind or cortex to it. The fibres of the former, however, are prolonged into this cortical layer, and the intermixture of the two forms of nervous substance is thereby effected (fig. 57).

The spinal cord is composed of certain columns of fibrous substance, in which a large number of the fibres take a longitudinal direction. These, in a great degree, enclose a distinct arrangement of vesicular matter, into which, however, as in the cortical layer of the cerebral hemispheres, some, at least, of the fibres of the external white matter are continued, intermingling with its elements. It may, therefore, be stated generally that in the brain the vesicular matter is external and cortical, and in the spinal cord it is internal and almost completely surrounded by the white fibrous matter. This difference of arrangement is probably to be ascribed to the fact, that throughout the whole course of the spinal cord nerves are being given off, whilst from the encephalon they come only from certain regions. In these regions the white matter is superficial; but in the hemispheres, from which no nerves proceed, it is deep-seated. We shall describe more minutely the disposition of the two kinds of nervous matter in the cerebro-spinal centre at a future page.

Of the Nerves and Nervous Centres in Invertebrate Animals.

Fig. 64.

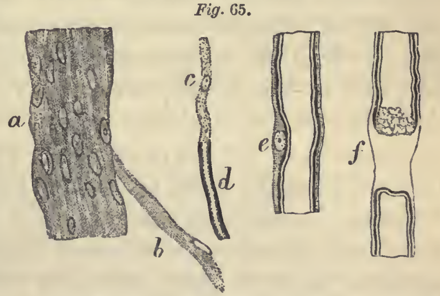
Nervous fibres of insects:—*a.* Transparent sheath. *b.* Nerve-fibres, with oval nuclei. *c.* Shews the bifurcation of the sheath.

The description above given applies to the human subject, and to the vertebrate classes generally. In all essential points, so far as the present state of our knowledge enables us to judge, the structural arrangement of the nerves and nervous centres of the invertebrate classes accords with this. Some differences, however, exist which require to be noticed here. In the lobster, the nerve-tubes are large; the tubular membrane has the same transparent, homogeneous appearance, which we have noticed in the vertebrata. But it incloses many delicate nuclei at various intervals. Within the tubular membrane, there is a very thin layer of the white substance of Schwann. The nerve-tubes are very transparent, and are much larger than the average size in vertebrata. Respecting the existence or structure of the gelatinous fibres, we can offer no remark. In insects and myriapoda, the nerve-tubes vary considerably in size; they are collected into bundles, and are surrounded by a transparent sheath of homogeneous membrane, which accompanies the larger ramifications of the nerve-trunks. The white substance of Schwann is not so obvious nor so constant in these nerves as in those of the lobster, and the existence of nuclei (fig. 64) makes them resemble closely the gelatinous fibres of the vertebrata. The anatomical characters of the vesicular nervous matter of invertebrata do not essentially differ from those of the same substance in the vertebrate classes, so far as our observation enables us to judge. The nerve-vesicles with nuclei and nucleoli are equally apparent in both, though in the former they are more transparent, and contain less pigment.

Of the Development of Nerve-fibres.—We can add nothing to the account given by Schwann of the development of nerve. The following is quoted from Dr. Willis's translation of Wagner's Physiology:—

"The nerves appear to be formed after the same manner as the muscles, viz. by the fusion of a number of primary cells arranged in rows into a secondary cell. The primary nervous cell, however, has not yet been seen with perfect precision, by reason of the difficulty of distinguishing nervous cells whilst yet in their primary state, from the indifferent cells out of which entire organs are evolved. When first a nerve can be distinguished as such, it presents itself as a pale cord with a longitudinal fibrillation, and in this cord a multitude of nuclei are apparent (fig. 65, *a*). It is easy to detach individual filaments from a cord of this kind, as the figure just referred to shews, in the interior of which many nuclei are included, similar to those of the primitive muscular fasciculus, but at a greater distance from one another. The filaments are pale, granulated, and (as appears by their farther development) hollow. At this period, as in muscle, a secondary deposit takes place upon the inner aspect of the cell-membrane of the secondary nervous cell. This secondary deposit is a fatty white-coloured substance, and it is through this that the nerve acquires its opacity. This is seen in fig. 65; superiorly, at *c*, the fibril is still pale; inferiorly, at *d*, the deposition of the white substance has occurred, and its effect

Fig. 65.



Various stages of the development of nerve:—*a*. Earliest stage. *b*. Detached fibre. *c*. Nucleated fibre in the lower part of which, *d*, the white substance of Schwann has begun to be deposited. *e*. Nucleus in a more fully-formed fibre between the white substance and tubular membrane. *f*. Displays the tubular membrane, the contained matter having given way.—(After Schwann.)

in rendering the fibril dark is obvious. With the advance of the secondary deposit, the fibrils become so thick, that the double outline of their parietes comes into view, and they acquire a tubular appearance. On the occurrence of this secondary deposit the nuclei of the cells are generally absorbed; yet a few may still be found to remain for some time longer, when they are observed lying outwardly between the deposited substance and the cell-membrane, as in the muscles (*e*). The remaining cavity appears to be filled by a pretty consistent substance, the band of Remak, and discovered by him. In the adult a nerve, consequently, consists, 1st, of an outer pale thin cell-membrane,—the membrane of the original constituent cells, which becomes visible, when the white substance is destroyed by degrees; 2nd, of a white fatty substance deposited on the inner aspect of the cell-membrane, and of greater or less thickness; 3rd, of a substance, which is frequently firm or consistent, included within the cells, *the band* of Remak."

The fully-formed vesicular matter exhibits the persistent state of the cells of primitive development. According to Schwann, the only change which the full-grown cell exhibits consists in an increase of size, and in the development of the pigmentary granules within. According to Valentin's description, the following is the process of development of the nerve-vesicles. In the very young embryos of mammalia, as the sheep or calf, the cerebral mass in the course of formation contains, in the midst of a liquid and transparent blastema, transparent cells of great delicacy with a reddish-yellow nucleus. Around these primitive cells, which we find likewise formed after the same type in the spinal cord, a finely granular mass becomes deposited, which probably is not at first surrounded by an enveloping cell-membrane. At this early period of formation the primitive cell still preserves its first delicacy to such a degree, that the action of water causes it to burst immediately. In proportion as the granular mass contracts itself within certain limits, a cell-membrane probably is developed around it, so that the vesicle gradually acquires the exact form and size, and its contents the proper characters, which belong to the fully-formed nervous corpuscle.

Of the Regeneration of Nervous Matter.—Our chief knowledge on this subject is with respect to the regeneration of the tubular fibres. Many years ago our countryman, Dr. Haighton, in making experiments to determine the functions of the vagus nerve, shewed that when a nerve is simply divided, without removing any portion of it, union would take place, and the nerve resume its proper office. If a considerable piece were excised, so as to leave much interval between the cut ends, there would be union after the lapse of some time, but not by true nervous fibres, nor in such a way as to restore the action of the nerve. It appears, however, from recent observations, of which those of Schwann, Steinruch, and Nasse are the most interesting, that true nerve-fibres may be developed in this uniting substance, but apparently in smaller numbers than in the nerve itself. The proof of the regeneration of the true nerve-fibres depends upon the restoration of the nerve's function, and the demonstration of the presence of proper nerve-tubes by microscopical examination. Perfect restoration of the action of the nerve does not generally take place, owing, most probably, to the fact that the central and peripheral portions of the same fibres do not always meet again. The central portion of a motor fibre might unite with the peripheral segment of a sensitive one, and thus the action of each would be neutralized.

Nothing satisfactory is known respecting the regeneration of the nervous matter of the brain or spinal cord after a loss of substance from injury or disease. When a portion of the brain is removed in animals, its place is supplied by new matter; but, whether this becomes true cerebral substance, future research with good microscopes must determine.

We refer, on the subjects of this chapter, to the various works on General Anatomy quoted in former chapters, especially to that of Henle; to Müller's, and Wagner's Physiology; to the articles Nerve, and Nervous Centres, in the Cyclop. Anat. and Phys.; to the fourth vol. of Sœmmering's Anat. by Valentin (German and French); to Valentin, über den Verlauf und die letzten Enden der Nerven; and to Bidder and Volkmann, Die Selbständigkeit des sympathetischen Nervensystem. Leipzig, 1842. The researches of Bidder and Volkmann on the sympathetic system are of great interest, if further observation shall confirm them. These authors describe the peculiar fibres of the sympathetic as originating independently of the spinal cord or brain. Their description of these fibres does not exactly accord with what we have seen of the gelatinous fibres, nor are we at present prepared to express any decided opinion respecting the accuracy of their observations, which are very favourable to the theory of the independence of the sympathetic system.

CHAPTER IX.

VITAL PROPERTIES OF NERVES AND NERVOUS CENTRES.—CLASSIFICATION OF NERVES ACCORDING TO THE VITAL ENDOWMENTS OF THEIR FIBRES.—STIMULI OF NERVOUS ACTION, MENTAL AND PHYSICAL.—VIS NERVOSA—ITS NATURE; IS IT ELECTRICAL?

Of the Vital Properties of Nerves and Nervous Centres.—There are no textures which exhibit such proneness to molecular change, under the influence of their proper stimuli, as nerve and muscle. It has already been stated in the first chapter (p. 56), that each of these tissues manifests its vital action in a different, although a very analogous way. Muscles, while they are capable of responding to other stimuli, almost invariably act in obedience to that of nerve; and the changes which muscular contraction produces are obvious to our unaided senses in the shortening of the muscle, and in its greater thickness and hardness. Even the alterations in the condition of its sarcous elements may be discerned by the microscope, and have been described at page 179.

The changes, however, which take place in nerve, when in action, are known to us only by the effects which they produce on the sentient mind or on muscular parts. There is no alteration in the physical appearance of the nerve or its fibres, which can be detected by our aided or unaided vision. Yet, from the rapidity with which stimuli applied to nerves produce their effects on distant muscular parts, from the instantaneous cessation of these effects on the removal of the stimulus, and the speedy renewal of them on its reapplication, we can refer the phenomena to nothing so well as to a *molecular change,* rapidly propagated along the course of the nerve from the point of application of the stimulus. And in the instantaneousness of its production, and the velocity of its propagation, we may compare it to that remarkable change in the particles of a piece of soft iron, in virtue of which it acquires the properties of a magnet so long as it is maintained in a certain relation to a galvanic current; these properties being instantaneously communicated when the circuit is completed, and as instantaneously removed when it is broken. A *state of polarity* is induced in the particles of the nerve by the action of the stimulus, which is capable of exciting an analogous change in other particles, whether muscular or nervous; whence results the peculiar effect of the nerve's influence.

Thus, if a nerve be distributed among muscular fibres in the manner described at a former page, it will be capable of exciting muscular contraction, and is properly a *muscular* or *motor nerve;* and it is so connected, at its origin, with the nervous centre, that a change there, whether induced by mental or by physical influence, may be readily communicated to it. When a nerve is distributed upon an expanded surface, as upon the skin or mucous membrane, or is otherwise favourably disposed for the reception of any physical stimulus from without, it will propagate the change induced by such stimulus to the nervous centre; and this change in the centre may produce an impression upon the mind, giving rise to a sensation; or it may affect a motor nerve connected with the excited one or arising from the nervous centre adjacent to it, and thus may indirectly excite muscular movement. When a nerve is capable of acting in the former way, it is called a *nerve of sensation*, or *sensitive;* when in the latter, it is an *excitor* of a motor nerve.

It is not necessary to suppose any intrinsic difference of structure in the nerves which are thus capable of producing effects so manifestly different. The action of a nerve depends upon the nature of its central and peripheral connexions. It cannot be motor, unless it be intimately connected with muscles; nor sentient, if its relation to the nervous centre be not such as will enable it to affect the sensorium commune. The terms *efferent* and *afferent* are only so far applicable to certain nerves, as they refer to the direction in which such nerves *appear* to propagate the change produced in them, or to the position at which the effects of the stimulation become manifest, that direction having reference to the point at which the stimulus is destined to act. In a motor nerve, the ordinary stimulus acts from the nervous centre; but a mechanical or electrical stimulus affecting such a nerve at any part of its course will cause contraction of the muscles supplied by it below the point of irritation. In the sensitive or excitor nerves, the usual situation from which the stimulus acts is at their peripheral distribution; but at whatever point a sentient nerve be stimulated, a sensation will be produced, which will be referred to those parts, and to those only, to which the fibres irritated are distributed; and wherever the stimulus be applied to an excitor nerve, it will, with equal effect, rouse its corresponding motor nerve to action. There are no good grounds for supposing that the molecular change consequent upon the stimulation of a nerve is limited to that part of the nerve which is included between the point stimulated and the centre, or the muscles, where the effect of the stimulation appears: on the contrary, it is not improbable, that, at whatever point the stimulus be applied, the whole length of the nerve-fibre participates in the change. This is not unlikely in the case of *motor* nerves. For a continued or violent irritation of a motor nerve in some part of its course, causing spasm or convulsive movement of the muscles it supplies, may be propagated along its whole length to the centre, and may there give rise to irritation of neighbouring fibres, whether motor or sensitive, exciting more convulsion and pain. The phenomena of many cases of epilepsy, in which the fit begins with irritation of a few muscles, may be referred to in illustration of this position. And it is equally probable as regards *sensitive* nerves. If the ulnar nerve be irritated where it passes behind the internal condyle, a sensation of tingling is excited, which is referred to the sentient surface of the ring and little fingers; and if the irritation be kept up, the skin of those fingers becomes tender to the touch, its sensibility being very much exalted. This fact cannot be explained unless upon the supposition that the molecular change in the nerve fibres, produced by the irritation, extends peripherad as well as centrad, exalting the excitability of their distal extremities.

At whatever part of their course sensitive fibres be irritated, the same sensation will be produced, whether the seat of irritation be the centre, the periphery, or the middle of their course, provided only the same fibres are irritated in the same degree. Nothing is more certain than that an affection of the central extremity of the nerve-fibres is sufficient to excite sensations precisely similar to those which the excitation of the peripheral portion of the same fibres would produce. Hence it is that a morbid irritation at the centre is frequently referred to the periphery; and that the sensation of tingling or formication, in the hand or foot, leg or arm, becomes an indication of cerebral or spinal disease. The remarkable fact, that persons who have suffered amputation will continue to feel a consciousness of the presence of the amputated limb long after its removal, derives some explanation from this doctrine. Two cases have lately come before us, in one of which the arm, in the other the leg, was amputated, so long before as forty years; yet each person had the sensation of his fingers or toes as distinctly as immediately after the operation. And not only is there, in such cases, the consciousness above referred to, but likewise, when the principal nerve of the limb is irritated, the patient complains of pains or tingling, which he refers to the amputated fingers or toes.

It may be stated, in confirmation of the view above taken, that in many cases of complete paralysis of a limb from *cerebral* disease, the patient is not conscious of its presence, and really feels as if it did not exist. We have known instances in which this unconsciousness has been so great, that when the paralyzed part came in contact with some sensitive portion of his body, the patient for a time believed it to belong to another person, or imagined it some entirely foreign substance. In such cases the affection of brain necessary to create the feeling cannot be produced in consequence of the morbid state of that organ.

The distinction which has been made between nerves of *common* and of *special* sensation, is indicated by the fact, that while a stimulus to the former causes pain, that to the latter gives rise to a peculiar or special sensation, as of light, sound, or taste. These nerves are so organized at their periphery as to be peculiarly adapted to receive impressions from the agents to which they specially respond: and in this, as well as in their connexion with some special part of the great centre of sensibility, consist their main anatomical peculiarities (see p. 56).

The same law of nervous action applies to these nerves as to those of common sensation. Thus, their ordinary mode of action is to propagate to the centre impressions made at the periphery; but irritation at any part of them may give rise to their peculiar sensation; and if the brain be stimulated at the part whence these nerves arise, similar sensations are produced. Such phenomena of vision and hearing, to which the term *subjective* has been applied, are familiarly known to practitioners, as not unfrequent forerunners of more serious symptoms of cerebral disease. Muscæ volitantes, ocular spectra, tinnitus aurium, are instances of these phenomena, which, although of every-day occurrence, ought always to excite the attention of the medical man, as indicating some departure from the normal state of the optic or auditory nervous apparatus. Pressure on the eyeball, a galvanic current passed through it,* rotation of the body, are capable of giving rise to similar phenomena, by exciting the retina, or the central connexions of the optic nerve. A sense of giddiness, similar to that produced by the means last named, is also a very common symptom of cerebral affection arising from a disturbed circulation, or from the blood being defective in

* A strong sensation of a flash of light may be produced by passing a galvanic current in the close vicinity of the eyeball.

one or more of its staminal principles, or vitiated by some morbid element.

The nervous trunks as they exist in different regions are usually compound; that is, they contain fibres of different endowments. In some situations, it is true, the fibres of one kind predominate so much as to give the trunk the physiological character which belongs to them; but it likewise enjoys, in a proportionate degree, the functions of those fibres, which are few in number. For example, the facial nerve, or *portio dura* of the seventh pair, is called motor, because it is almost wholly composed of motor fibres; but it contains, besides, in very much smaller number, some sensitive filaments, which it probably derives from anastomoses with neighbouring nerves. The third, fourth, and sixth pairs of nerves may be quoted as of similar constitution to the facial. In the ramifications of the fifth nerve, on the other hand, the filaments of sensation are predominant; those of motion being much fewer, and confined to the branches of its inferior maxillary division.

It is at the points of emergence of the roots of the nerves from the nervous centres that we find the most complete isolation of function. This is well exemplified in the spinal nerves and in the fifth pair. These nerves emerge from their respective centres by two bundles of fibres, of which one is sensitive, the other motor; the former having almost always the distinctive features of greater size than the latter, and of having a ganglion formed upon it. But, even in these instances, it has lately been made a matter of question whether the smaller root, which experiment has satisfactorily shewn to be motor in its function, does not also contain a very slight proportion of sensitive filaments.

The stimuli by which the action of nerves is ordinarily provoked are of two kinds, *mental* and *physical*. In all voluntary actions, an act of the mind is the excitant of the nerve. Sensations are caused by the influence of physical agents upon nerves, which communicate with the *sensorium commune*. The change in the nerve, by reason of this communication, gives rise to a corresponding affection of the mind. It is wonderful how quickly such changes are propagated, and with what precision they are perceived by the mind, although the physical excitant may itself be a fine point invisible to the naked eye, applied with the slightest force, and coming in contact with a spot equally difficult of appreciation. If the communication between the nerve and the centre be cut off, the will can exert no influence upon the muscles supplied by the nerve below the section; nor will the mind perceive any stimulus applied to parts which derive their nerves from it below the separation. And the reason is obvious; the solution of continuity of the nerve interrupts the propagation of the change which the mental or physical stimulus excites in it. In the case of the voluntary nerve, the mental stimulus is propagated no further *peripherad* than the point of section; and in that of the sensitive nerve, the change travels no further *centrad* than the same point. That the interruption is caused solely by the solution of continuity, and not by any alteration in the properties of the nerve, is proved by the fact that the lower segment of the motor nerve will still continue to respond to a physical stimulus. Mechanical or chemical irrition, or the passage of an electric current across it, will cause its muscles to contract. Such a degree of injury to a nerve as will destroy the continuity of the nervous matter within the tubular fibres is likewise sufficient to destroy its power as a propagator of nervous change. This effect will be produced by tying a ligature very tightly round a nerve, or by pressing it very forcibly between the blades of a forceps. The paralysis which results from the compression of a nerve by a tumor, or in any other way, is no doubt due to a similar solution of continuity in the nervous matter.

From these facts we draw the important inference that, in propagating the influence of a stimulus, either from periphery to centre, or *vice versâ*, nerves are not mere passive conductors. The whole extent of the fibre between the point stimulated and its peripheral or central connexion is the seat of change. How necessary, then, to the normal action of nerves must it be to preserve their physical condition in a healthy state! A morbid fluid impregnating a nerve at any point may irritate it, or may suspend or destroy its inherent property by modifying its nutrition. It is thus, likewise, that nerves may be paralysed by soaking them in a solution of opium, or of belladonna, aconite, tobacco, or other powerfully sedative or narcotic substances, or that they may be unduly excited by applying a solution of strychnia. The contact of a solid body with a nerve may irritate and keep up a continual state of excitement, if it do not destroy its properties. A spicula of bone in contact with nervous fibres is often the cause of the severest forms of neuralgia. That alteration of nutrition which we call inflammation may produce like effects. Various physical agents are followed by similar consequences. The benumbing influence of cold is explained in this way. Exposure to a continuous draught of cold air is a frequent cause of facial paralysis. How instantaneously will the giving way of a carious tooth occasion toothache, by exposing the nerves of its pulp to the irritating action of the air, or of the fluids of the mouth! And heat is equally injurious to the physical constitution, and, consequently, to the action, of nerves.

The organic change, whatever be its intrinsic nature, which stimuli, whether mental or physical, produce in a nerve, developes that wonderful power long known to physiologists by the name *vis nervosa,* the nervous force. This force is more or less engaged in the play of all the vital functions, whether organic or animal. In the former its office is to regulate, control, and harmonize, as will be hereafter explained; in the latter, it is the main-spring of action, without which none of the phenomena can take place. It is the natural excitant of muscular motion, and the display of that wondrous power depends upon its energy. Unless there were vigour in the development and application of the nervous force, a well-formed muscular system would be of little avail, for it would quickly suffer in its nutrition if deprived of that exercise which is so necessary to it.

Although the workings of the mind are doubtless independent of the body, experience convinces us that in those combinations of thought which take place in the exercise of the intellect, the nervous force is called into play in many a devious track throughout the intricate structure of the brain. How else can we explain the bodily exhaustion which mental labour induces? The brain often gives way, like an overwrought machine, under the long-sustained exercise of a vigorous intellectual effort; and many a master-mind of the present or a former age has, from this cause, ended his days "a driveller and a show." A frequent indication of commencing disease in the brain is the difficulty which the individual feels in "collecting his thoughts," the loss of the power of combining his ideas, or impairment of memory. How many might have been saved from an early grave or the madhouse, had they taken in good time the warning of impending danger which such symptoms afford! The delicate mechanism of the brain cannot bear up long against the incessant wear and tear to which men of great intellectual powers expose it, without frequent and prolonged periods of repose. The precocious exercise of the intellect in childhood is frequently prejudicial to its acquiring vigour in manhood, for the too early employment of the brain impairs its organization and favours the development of disease. Emotion, when suddenly or strongly excited or unduly prolonged, is most destructive to the proper texture of the brain, and to the operations of the mind. Our lunatic hospitals afford many examples of men the working of whose minds has been wholly or partially destroyed by the shock which a sudden reverse of fortune, or the loss of some near and dear relative, may have occasioned. Constant or frequent excesses in the use of ardent spirits may probably be thus injurious in two ways; first, by the direct influence of the alcohol on the cerebral fibre itself, producing a chemical alteration in the nervous substance; and secondly, by the frequent mental excitement which the use of such a stimulus induces.

Can we form any conception of the nature of this wonderful power, which is so intimately connected with the functions of our bodies and with the working of our minds? That it presents many points of resemblance to electricity, a comparison of the laws of these two forces leaves no room to doubt; although there are abundant reasons for questioning their identity. The comparison may be best instituted between the nervous power and the force of voltaic electricity, or current affinity, as it has lately been called, which is developed in the galvanic battery. For the production of this force the ordinary requisites are two dissimilar metals, and an interposed compound liquid. When the metals are brought into contact with each other, a chemical action immediately commences, and an electric current sets in a definite direction, namely, from the metal which exerts the greatest affinity for one of the elements of the interposed liquid towards the other metal. Thus if zinc, platinum, and dilute sulphuric acid be used, the fluid is decomposed; its oxygen is attracted to the zinc, which being oxidised and uniting with sulphuric acid, sulphate of zinc is rapidly formed, and dissolved as quickly as formed, in the liquid; its hydrogen is evolved at the platinum. So long as there is fluid for decomposition, and so long as contact between the metals is maintained, these phenomena will continue. During the continuance of these chemical actions, the metals as well as the interposed fluid are supposed to be in a peculiar molecular condition, upon which the development of force in a curreut form depends. Commencing from the immersed portion of the zinc, each particle, whether of metal or fluid, communicates its peculiar state to that which succeeds it, until the whole circuit, from the zinc through the fluid to the platinum, and back again to the zinc, is in the same state, one, namely, of *polarity* or *electrical tension*. A similar state may be induced in glass, sealing-wax, &c. by friction; or in two dissimilar metals in intimate contact, by heating them at the place of junction; or in one metal, as a coil of platinum wire, by heating it unequally (thermo-electricity). The simple contact, indeed, of two plates of different metals with perfectly clean surfaces is sufficient to excite a state of polarity in each.

In the development of the galvanic current in the battery, one plate or metal may be regarded in the light of the generator of force, the other as its propagator or conductor. The former has therefore been called the *positive*, the latter the *negative* pole. The absolute contact of the metallic plates themselves is not necessary. It will suffice if they be connected by any material which is itself capable of serving as a conductor. A piece of platinum wire, for instance, extended between the two plates, although it actually connects only a very small portion of the surface of each, will answer the purpose. From such an arrangement it may be concluded that, during the development of the galvanic current, the conducting metal is in a state similar to that of the generating plate, for the temperature of the conducting wire is raised considerably; and, when there is much energy of action, the wire is melted.

The existence of a galvanic current is readily detected, even when of feeble intensity, by certain phenomena, which are now familiar to those who conduct such investigations. If the poles of a battery be connected by conducting wires with a delicate galvanometer (electro-dynamic multiplier), the needle is obviously deflected during the passage of the current, and returns to its previous position whenever the current is interrupted. By making and breaking the connexion, in rapid succession, the needle moves to and fro with corresponding rapidity and energy. So delicate is this test of galvanic action, that it will detect even the very feeble current which results from the heating of two dissimilar metals, or from the partial heating of a coil of platinum wire. As this is the most delicate test, so is it also the most constant, and it has the additional advantage of enabling the observer to judge of the direction of the current, from the position which the needle assumes under the electric influence.

When a galvanic current is made to pass through certain liquids, as dilute sulphuric acid, solution of iodide of potassium, of sulphate of copper, &c., it induces such an amount of disturbance of the attractions existing in them as to cause their decomposition, and give rise to chemical actions of a similar kind to those which take place in the generation of the current (electrolysis). This, therefore, becomes a test of the presence of galvanic action. The decomposition of iodide of potassium will detect the existence of a current developed by a single pair of plates, and iodine will be set free at the positive pole.

Further tests of the presence of galvanic action are found in the magnetization of a steel needle placed within a coil of wire through which the current is made to pass; and in the evolution of heat and light, which takes place when the circuit is completed or broken. This latter effect, however, does not occur from currents of very feeble intensity.

Let us inquire how far the phenomena of the nervous force correspond with those of this current electricity, and whether it will respond to any of the tests just described.

It has already been remarked, that the instantaneousness with which nervous power is developed, when a mental or physical stimulus is applied to a nerve, resembles remarkably the rapid evolution of the galvanic force throughout the whole circuit, the instant the necessary contacts are completed. And both cease with equal rapidity when the conditions for their production are destroyed.

Some analogy is apparent in the conditions which are requisite for the development of both forces. The dissimilar metals and the interposed fluid, which we have seen to be necessary for the production of the galvanic force, may have as analogues for the development of the polarity of nerves, the two kinds of nervous matter (the vesicular and fibrous), and the blood. Nervous power is never developed from a centre without the conjoint action of these two kinds of nervous matter. The analogy fails, however, when we compare the relation of the metals in the battery with that of the gray and white matter in the nervous centre. The former need not have any connexion but such as a conducting wire of ever so minute dimensions passing from one to the other is capable of effecting; that is to say, union of a few points of one metal with as many of the other, is sufficient for the generation and transmission of the polar state. In the nervous centres, however, the points of contact are probably most numerous. The vesicles of the gray matter certainly are brought most extensively into connexion with the nerve-fibres; and there is much to justify and confirm the opinion that each fibre is connected with a vesicle, and that each vesicle, at least of the caudate kind, may be regarded as the point of departure of one or more fibres. If such an arrangement exist, we may regard each nerve-vesicle, and the fibres emerging from it, with the blood-vessels which play around it, as a distinct apparatus for the development of nervous polarity.

There appears to be a provision for the insulation of the central axis of each nerve-fibre in the white substance of Schwann; but there is no such arrangement for insulating the vesicles. In like manner, we can insulate the galvanic current by covering the conducting wire with silk, or some other non-conductor, and thus cause it to pass through an indefinite length of wire disposed in coils, or through any number of separate wires disposed parallel to each other, which may be brought into connexion with the metals.

These remarks are clearly most applicable to those nervous actions which emanate *from* a centre. But in those in which the nervous force is propagated *to* a centre, as when pain is excited by touching a nerve, or in the excitation of the motor nerve of an amputated limb by artificial stimuli, the analogy of the mode of its development with that of the galvanic force is not so obvious. Still, when we remember how easily thermo-electric currents may be excited by the disturbance of the equilibrium of heat in a wire of even a single metal, it seems not unreasonable to refer this excitability of nerve to some similar proneness to change in it.

Nothing is more certain than that a very slight mechanical or chemical stimulus to a nerve, whatever be its proper vital endowment, is capable of producing in it that state of polarity on which we suppose the manifestation of nervous force to depend: and it seems not incorrect to imagine that, in the battery, the point of departure of the galvanic action may either be at the poles or at the battery itself, according to the place at which the completion of the circuit takes place; thus affording a more marked analogy to the two kinds of nervous actions above referred to. Thus the conducting wires may be in contact with each other, and with their respective metals; but, if there be no fluid interposed, there is no action. The instant the fluid is added, the current begins; and in this case its point of departure may be regarded to be from the battery — in analogy with those nervous actions which proceed from the centre. On the other hand, the arrangements of the battery itself may be perfect, but action will not begin until the circuit is completed by bringing the conducting wires into contact. In this case, the polar change may be said to commence at this point of contact, and to travel to the battery, in a manner analogous to that in which nervous action is propagated from the periphery to the centre. In both cases, moreover, so long as galvanic action continues, the *whole* apparatus is in the polar state: and so long as nervous action continues, the particular nervous apparatus involved (vesicular matter and nerve-fibre) must be considered to be in a state of polarity through its *whole* extent.

Thus far we remark unquestionable analogy in the mode of development and of propagation of the electrical and nervous forces. We must not, however, omit to notice the following points, in which the analogy does not hold good. In the development of nervous power, there is nothing, so far as our present anatomical knowledge enables us to decide, resembling that completion of the circuit, which is the necessary prelude to galvanic action, or the interruption of it, which is followed by the cessation of that action. The mental or physical stimulus, which must be regarded as a necessary element in every nervous action, stands in lieu of the former; but how could it accomplish the completion of a nervous circuit is a question at present involved in the greatest obscurity. It is, indeed, a favourite notion with some, that the looped arrangement of the peripheral nerve-fibres, in muscles and on some sentient surfaces, forms part of a nervous arc, which is completed at the centre; nor is it impossible to conceive a mechanism by which the completion or interruption necessary for the development or the stoppage of the nervous power might be accomplished. But it would be hazardous to speculate on such a subject until anatomical research has revealed to us more information respecting the exact disposition of the elements of the vesicular matter.

The gelatinous fibres appear to want the provision which we have noticed in those of the tubular kind for insulating the nervous power. They supply the unstriped muscular fibres, which probably require a stimulus less definite, as well as of less intensity, than that necessary to excite and regulate the action of the striped fibres. This difference of character in the conducting fibres is worthy of note in making comparison between the respective modes of action of the nervous and electric forces.

We come now to inquire whether, by means of the ordinary tests for electricity mentioned in a former page, we can obtain any evidence of the identity of the nervous and electrical forces. The results of experiment certainly afford no support to the advocates of the electrical theory; and indeed it will be seen that there are difficulties in the way of obtaining the necessary conditions for a satisfactory result, which of themselves invalidate the experiments which have been reported to prove favourable to that theory.

Attempts have been made to affect the galvanometer by bringing the nerves of living animals into connexion with it. This is done by inserting wires into the exposed nerve, and attaching their opposite extremities to the galvanometer. When the nervous power is excited so as to cause muscular contraction, the needle, it is said, is deflected.* The experiment, however, has failed in the hands of

* David, quoted by Müller, p. 685.

Prevost and Dumas, who are advocates of the electrical theory, as well as in those of Person, of Müller, and of Matteucci; and on several trials we have been unable to observe the slightest movement of the needle. Person connected the wires of a galvanometer with the surfaces of the spinal cord in kittens and rabbits, in which spasmodic action of the muscles had been excited by the influence of nux vomica, and could not discover any evidence of electrical action. It has also been affirmed that needles introduced into the nerves of a living animal become magnetic, so as to attract iron filings. No such result, however, could be obtained by Müller, or by Matteucci, from their repetition of these experiments. The latter philosopher took the precaution of employing astatic needles for the purpose, but could discover no trace of magnetization. He also introduced the prepared limbs of a frog into the interior of a spiral covered on its inside with varnish: the extremities of this spiral were united to those of another smaller spiral, into which he introduced a wire of soft iron. The nerves of the frog were irritated to excite muscular action, and at the same time Matteucci sought to ascertain if an induced current would traverse the spirals, and magnetize the wire. But, he adds, all his endeavours were useless.

No one has tried to obtain a spark from a nerve during its action, as a test of the electrical nature of the nervous power. Nor have any experiments been devised with a view to ascertain whether decompositions similar to those which occur in electrolysis may be effected by it. The separation of certain elements from the blood, in the various secretions, has, indeed, been attributed to a kind of electrolytic influence of the nerves upon the secerning organs. But it has been proved that the secretions may go on to a considerable extent independently of nervous influence, and it seems highly probable that the nervous system can affect the act of secretion only through its influence upon the blood-vessels of the secreting organ.

But even were it certain, that an electrical current passes along the nerve-fibres during nervous action, it does not seem likely that the required evidence of such a current could be obtained from any of the experiments above detailed. For if the nerve-tubes are to be regarded as insulated conductors, of which the central axis is the active portion, and the white substance of Schwann merely the insulator, sinking a needle between these fibres will not obtain that contact with the true conducting material which is necessary to affect the galvanometer. Let it be remembered, that these nerve-fibres are of microscopic size; and that, when a needle is sunk into a bundle of them, it does not pierce the nerve-tubes, but passes in between them, and is separated from their central axes by the insulating structure. And were the electric current, passing through such minute conductors as nerve-fibres, of sufficient intensity to magnetize a needle, it is scarcely possible to conceive that it would be completely or perfectly insulated by the delicate membranes which invest the central axis. Yet, without some provision for very complete insulation of the several conductors in such a bundle as a nervous trunk, it is obvious that disturbances must continually arise from the secondary currents induced in neighbouring fibres by the electricity passing through those in action.

The proofs, therefore, of the passage of an electric current through the nerve-fibres during nervous action must be held to be altogether defective. Not only is experimental evidence wanting to support the electrical theory, but certain facts are admitted which greatly invalidate it. Of these, a very important one has been adduced in the preceding paragraph. The following may be added, some of which have already been adduced by Müller.

1. The firm application of a ligature to a nerve stops the propagation of the *nervous power* below the points of application, but not of *electricity*. The nervous trunk is as good a conductor of electricity after the application of the ligature as before it.

2. If a small piece of a nervous trunk be cut out, and be replaced by an electric conductor, electricity will still pass along the nerve, but no nervous force, excited by stimulus above the section, will be propagated through the conductor to the parts below.

3. Nervous fibre is not a better conductor of electricity than other tissues. Matteucci assigns to muscle a conducting power four times greater than that of nerve or cerebral matter; and Weber states that no substance in the human body is so good a conductor as the metals. From our own observations on this subject, made with the *most delicate* instruments, we are led to state that both nerve and muscle are *infinitely worse* conductors than copper, and that we have failed in detecting any appreciable difference in the conducting power of these two animal substances. In fact, their power of conduction does not rank above that of water holding in solution a small quantity of saline matter.

From the preceding review of the arguments for and against the theory of the identity of the nervous force and electricity, we are led rather to reject than to adopt it. The same reasons induce us to regard the nervous force as a power developed in the nervous structure under the influence of appropriate stimuli; as muscular force is developed in muscle under similar influence. Both tissues are characterized by their tendency to assume a polar state, different in each, although analogous, in obedience to certain excitants. That this polarity bears a remarkable analogy to that which may be produced in inorganic matter is evident. Further observation and research conducted with a full knowledge of the details of anatomy, as well as of the laws of the polar forces as displayed in inorganic substances, will doubtless throw great light on this intricate subject; for, as Faraday remarks, if there be reasons for supposing that magnetism is a higher relation of force than electricity, so it may well be imagined that the nervous power may be of a still more exalted character, and yet within the reach of experiment.*

Of the Electrical Fishes.—The fact that some fishes possess a peculiar electrical apparatus, which they are enabled to discharge under voluntary influence, is supposed by the adherents of the electrical theory to favour their views. The *torpedo*, the *gymnotus electricus*, or electrical eel, and the *silurus electricus*, are the best known of the electrical fishes. From the two former, the most unequivocal evidence has been obtained by Walshe, Davy, Linari, Matteucci, and recently by Faraday, that electricity is discharged. Conductors or non-conductors are affected by the electrical apparatus of these fishes just as by ordinary electricity: a chain of several persons, of whom those at the extremities touch the fish, feel the shock as they would that of a Leyden jar. The sensation produced by the shock from the fish is exactly that which is caused by accumulated electricity as developed by the ordinary machine. A spark has been obtained during the discharge: chemical decomposition or electrolysis has been effected by it. The galvanometer is also readily disturbed, and indicates that the current passes from the anterior to the posterior part of the animal. And a needle has been made a magnet when placed in a helix through which the current passes. These effects have been obtained from the torpedo and the gymnotus.

It is further shewn, that the electricity cannot be developed in these animals if the organ be removed, or if its communication with the brain be cut off. If the nerves of the organ of one side be cut, it will cease to develop electricity; but the opposite organ will continue to act perfectly. When the organ is partially cut away, the remaining portion continues to discharge; or, if some of its nerves be cut, that portion of which the nerves are entire will continue to develop electricity. The nerves excite some change in

* Phil. Trans. 1839.

the organ which causes the development or discharge of electricity, but no traces of an electrical current can be detected in the nerves themselves. If the nerves of an electrical organ be cut, irritation of those segments of them which adhere to the organ will excite discharges, just as the irritation of muscular nerves under similar circumstances will cause contractions; or direct irritation of portions of the organ itself will produce discharges (Matteucci). Any general excitation of the nervous system will cause discharges; thus strychnine, while it throws the muscular system into spasms, provokes frequent and violent discharges of the electrical organs.

From these observations, it seems impossible to adopt any other conclusion than that the electrical organ is the *generator* of the electricity; or, at least, that it may collect and accumulate the electricity generated all over the body in the ordinary nutritive processes. This latter opinion, however, is rendered unlikely from the imperfect conducting power of animal substances, unless further research should develop some channels by which electricity generated at a distance might be conveyed to the electrical organ. Whatever view of the case be adopted, it is difficult to discover in the facts above stated respecting the electrical fishes any support to the electrical theory of nervous power. On the contrary, the very existence of a peculiar organ for the specific purpose of generating electricity would appear adverse to such a doctrine. Were the nervous centres the source of electricity, surely an arrangement of a less complex character, and deviating to a less extent from the natural structure of other fishes of the same genus, would have sufficed for the manifestation of the peculiar power of the electrical fishes.

Some insects (the glow-worm for instance), and other creatures, possess the faculty of generating light. The power resides in a particular organ, and is regulated by the nervous system. It is strikingly analogous to that by which electricity is developed. Yet no one would assign the nervous system as the source of the luminous emission. Nor are we justified in affirming from the one instance that the nervous power is electricity, any more than we should, from the other, be authorized in asserting that the nervous power is light.

On the subjects discussed in this chapter, reference is made to Müller's Physiology by Baly; Daniell's Chemistry; the articles "Animal Electricity" and "Animal Luminousness," in the Cyclop. Anat. et Physiol.; Matteucci, Traité des Phénomènes Electrophysiologiques des Animaux.

CHAPTER X.

ARRANGEMENT OF THE NERVOUS SYSTEM IN VERTEBRATA.—IN INVERTEBRATA.—NERVOUS CENTRES IN MAN.—THEIR COVERINGS OR MENINGES.—THEIR VENOUS SINUSES.—THE SPINAL CORD.—THE ENCEPHALON.—THE CIRCULATION WITHIN THE CRANIUM.

The leading subdivision of the animal kingdom into Vertebrate and Invertebrate animals is so obviously sanctioned by the disposition of the nervous system peculiar to each, that no naturalist hesitates to adopt it. In the *vertebrate* animals, an osseous or cartilaginous column, composed of separate pieces united by amphiarthrosis, forms the principal support and bond of connexion for the other parts of the trunk. This column encloses a canal, within which is placed that portion of the nervous centres called the spinal cord, or marrow, with some of its nerves. At its anterior or upper extremity, the component pieces of the column are so modified as to form a dilated cavity, the cranium, in which another portion of the central nervous system, the brain, or encephalon, with part of the nerves connected with it, is contained. In the *invertebrate* animals generally there is no internal skeleton, if we except the slight traces which exist in the cephalopodous mollusks; but in many of them a modification of the external integument affords the requisite amount of protection and support to the soft tissues and organs. The nervous system, the central part of which is disposed either in detached masses, or in a series along the abdominal surface of the animal, receives no special protection from this external skeleton.

The brain and spinal cord, in the vertebrate classes, form a central axis with which all other parts of the nervous system are connected. The former is evidently an aggregate of gangliform swellings, each possessing the characters of a nervous centre, but so connected with the others, that their functions are in no small degree mutually dependent. The latter has, throughout its entire length, all the characters of one uniform nervous centre, of cylindrical shape; but experiment has shewn that, if divided into segments, in animals tenacious of vitality, each portion may exert an independent influence on that segment of the body whose nerves are connected with it. From this fact we may properly regard the cord also in the light of a ganglion compounded of smaller ones, which have been, as it were, fused together. And certain anatomical indications in the lower animals, as well as in man, favour this view; thus, in the common gurnard (*trigla lyra*), there is a series of gangliform swellings situate on the posterior surface of the cervical portion of the cord at its upper part, from which large nerves pass off to the feelers; and in all animals the cord exhibits a distinct enlargement, at each segment with which large nerves are connected, or a contraction, if the nerves be of small size and of comparatively little physiological importance.

The cerebro-spinal axis, with the nerves pertaining to it, constitutes the greatest portion of the nervous system of the human subject and of the vertebrate animals. The sympathetic system, however, is connected with a large number of those parts on which the principal organic functions depend. This portion of the nervous system always bears a direct relation in point of development to that of the cerebro-spinal portion, with every part of which it is very intimately associated. If we except the olfactory, optic, and auditory nerves, there is no nerve with the origin of which it does not form a connexion. Its segments remain separate, as distinct ganglia, connected, however, by intercommunicating cords passing from one to the other, by which the continuity of the chain on either side of the vertebral column is maintained. In mammals and birds the sympathetic is fully developed; but in some reptiles and fishes it is partly deficient, and its anterior part, which is wanting, is supplied by the vagus nerve. In the cyclostomatous fishes, as the lamprey, it is wanting altogether; and the vagus seems to supply its place. In no animal is it so fully developed as in man.

Arrangement of the Nervous System in Invertebrata.

It is foreign to the purpose of this work to enter into details of comparative anatomy. The following paragraphs are merely intended to call the reader's attention to the general plan of the nervous system in the Invertebrata. The arrangement adopted is that suggested by Professor Owen.

The Invertebrate animals may be classed in three groups, according to the prevailing type of arrangement of the nervous system. 1. The first, or *Nematoneurose*, exhibits no other trace of nervous system than is to be found in simple threads or filaments. In the *asterias*, one thread surrounds the mouth, and others pass from it to the rays; and in the *strongylus gigas*, a slender nervous ring surrounds the upper part of the gullet, and from it a single thread is continued along the ventral surface to the opposite extremity, where another nervous loop is found surrounding the anus. No distinct evidence of the existence of ganglia in animals included in this group has been obtained. It would be premature, however, to suppose that the absence of gangliform swellings implies that of vesicular nervous matter.

2. The second group of animals is designated *Heterogangliate*, from the

unsymmetrical disposition of the nervous system. The principal portion of it consists in a ring surrounding the gullet, on which one or more ganglia are placed. In the *ascidia mamillata* there is but a solitary ganglion, which regulates the orifices of ingestion and egestion by nerves which it sends to their respective sphincter muscles. And in all the other classes of mollusks the nervous system is the more complex, as the kind and number of the vital actions demand a higher degree of organization. In conchifera, for instance, ingestion of the food, respiration, and locomotion have distinct organs assigned to them, and accordingly the nervous system is so disposed that there is a nervous centre or ganglion in immediate relation to the principal organs connected with each of these functions. Thus, in the more perfect animals of this class we find, 1. two *œsophageal* ganglia situate near the mouth, connected to each other by nervous filaments, which form a ring round the gullet. These ganglia are connected with all the rest, and probably exercise an influence upon them, as the principal centre of the nervous system or the brain. 2. There is a *branchial* ganglion, which presides over the function of respiration. When there is but one respiratory organ, this ganglion is single; but it is double when there are two branchiæ. From this source are supplied not only the organs of respiration themselves, but also the muscles upon which the respiratory movements depend. The posterior adductor muscle, the mantle, and intestine, derive nerves from it. 3. We find a *pedal* ganglion, which is immediately connected with the locomotive function. This ganglion exists only in those genera in which a muscular organ called the foot is developed, and its size is always in direct proportion to the muscular power of that organ: it is situated at its base, and imbedded in it. We find it, therefore, in the mussel (*mytilus*), but not in the oyster. The development of organs of sense in the higher animals of this group demands an increased development of the cerebral ganglion, as is the case in the gasteropod and cephalopod mollusks. And the great powers of locomotion enjoyed by the latter animals require a high development of the pedal ganglion, and a multiplication of smaller ganglia in connexion with the muscular apparatus of their arms or tentacles. These organs are supplied with nerves from the subœsophageal ganglion; and, where suckers exist upon the arms, an additional series of ganglia is provided, which seem to exert an especial influence in the exercise and the maintenance of their suction power.

3. The third, or *Homogangliate* group, is distinguished by the symmetrical arrangement of the nervous system. The articulate classes furnish examples of this type. A bilobed ganglion is situated above the œsophagus, and is connected with the organs of sense when they are present. From this there proceeds on each side of the œsophagus a nervous cord to a pair of ganglia beneath that canal, and therefore on the ventral surface. To these succeed, in most of the articulata, and likewise on the ventral surface, a pair of ganglia for each segment, from which are supplied the nerves to that segment. The ganglia are connected throughout, however, by cords of communication from the cephalic to the caudal segment. The number of pairs of ganglia is always in accordance with the number of segments of the animal; and, if some of these segments be fused together, a similar coalescence of the ganglia takes place. This is observed in insects in the change from the larva to the perfect state; and, in some genera of crustacea, the permanent form of the nervous system has obvious relation to peculiarity in the shape of the body. The annular arrangement of the ganglia in the body of the common crab (*cancer*), and of

the king-crab (*limulus*), is evidently explained by reference to the compressed form of the body, and the articulation of the legs around it.

Some additional ganglia are met with in a few animals of the homogangliate group, which seem to represent rudimentary conditions of the sympathetic system. These have been best observed in insects, and they are described under the name of stomatogastric ganglia. They are two or more in number, connected by delicate filaments with the cephalic ganglia; and they give off long nerves, which supply the digestive organs and the dorsal vessel, or heart, and which, in some instances, unite with small ganglia in the abdomen to be distributed on the viscera of that cavity.

Of the Spinal Cord and Brain.—The cerebro-spinal centre is enclosed in certain membranes or *meninges,* which are three in number: the *dura mater,* the *arachnoid,* and the *pia mater.*

The *dura mater* consists of white fibrous tissue. It is thick, very strong, and flexible, without being elastic. Its fibres are disposed on different planes, but freely intermingle. At certain situations, it separates into two layers to form the venous canals, which are called *sinuses.* The inner surface of the cranial cavity is covered by dura mater, which adheres closely to the bones, and serves as an internal periosteum to them; and certain processes of the dura mater pass into the interior of the cranial cavity, dividing it into compartments, which contain certain segments of the encephalon. These processes are, 1. The *falx cerebri*, which extends from the crista galli to the occiput along the line of the sagittal suture, and forms a vertical septum between the hemispheres of the brain. 2. The *tentorium cerebelli,* which is attached to the occipital bone along the groove for the lateral sinus, and to the posterior superior edge of the petrous bone. This process forms a vaulted roof to the compartment which contains the cerebellum, and extends between the upper surface of that organ and the inferior surface of the posterior cerebral lobes. In some animals, the cat, for instance, it is partially replaced by bone. 3. The *falx cerebelli,* a small nearly vertical process which descends from the internal occipital protuberance, and occupies the notch between the hemispheres of the cerebellum.

In the spinal canal, the dura mater does not adhere to the inner surface of the spinal bones as a periosteum. On the contrary, it is separated from it by a soft unctuous fat mixed with very numerous veins. It adheres pretty closely to the anterior common ligament which intervenes between it and the bodies of the vertebræ, and seems to be continued from the cranial dura mater at the foramen magnum as a funnel-shaped process of that membrane adapted to the shape of the spinal canal. It ends in a blunted extremity in the sacral canal, and is tied down in that situation by certain filiform processes, of which the central one is attached to the coccyx. The spinal dura mater is evidently much more capacious than is necessary merely to contain the spinal cord, and therefore it generally has a loose and flaccid appearance. During life it is kept tense by the fluid which surrounds the cord. The dimensions of the canal of the dura mater vary with those of the spinal canal. It is wider, therefore, in the neck and loins, and narrow in the back. In the lumbar and sacral regions it forms a wide sac around the leash of nerves called *cauda equina.*

The dura mater, in both cranium and spine, exhibits numerous perforations for the transit of nerves from the contained centre to the peripheral parts. In the spinal region each of these perforations is subdivided, by a vertical slip of the membrane, into two foramina, which correspond to the anterior and posterior roots of the spinal nerves, and extend on each side down to the lower part of the sacral region.

The blood-vessels of the dura mater are very numerous. Those of the cranial membrane communicate freely with those of the bones. Hence, when separated from the cranium, the external surface of the dura mater has a rough appearance, from the number of blood-vessels which have been torn. This membrane derives its supply of arterial blood from the ophthalmic and ethmoidal arteries in front; in the middle, from the internal maxillary artery by the *middle meningeal*, which enters the cranium by the foramen spinosum, and by small branches from the internal carotid, called the *inferior meningeal* arteries. Posteriorly the vertebral, the occipital, and the ascending pharyngeal supply branches which go by the name of *posterior meningeal arteries.* The arteries of the spinal dura mater come from the deep cervical, the occipital, and the vertebral, in the cervical region, from the intercostals in the back, and from the lumbar arteries in the loins. These vessels pass in at the vertebral foramina, and send branches to the bones as well as to the spinal membranes.

The veins of the dura mater in the cranium constitute a remarkable portion of the vascular system of that cavity. The venous radicles collect the blood from the dura mater, and from the bones of the skull; large veins are formed on the former membrane, and distinct canals in the osseous diploë, figured at page 107. These all tend to certain venous channels, rigid canals, formed by the separation of two layers of the dura mater, which are lined by processes of the inner membrane of the venous system, and are so placed as to collect the blood from all parts of the cranium. These canals, *sinuses of the dura mater*, receive likewise the venous blood of the brain. The largest sinuses are the *superior longitudinal* and the *lateral sinuses*. The former extends along the convex edge of the falx cerebri, commencing very small by receiving veins from the ethmoid and frontal bones, and terminates in a reservoir common to it and other sinuses at the internal occipital protuberance (*torcular Herophili*). It thus serves to collect blood from the superior and lateral parts of the dura mater, from the vault of the cranium, and from the hemispheres of the brain; the veins of the latter entering it obliquely forwards. The *lateral* sinuses are lodged in tortuous furrows, which mark the occipital, the parietal, and the temporal bones. They are two in number, and extend on each side from the torcular Herophili to the jugular foramen, where they are continued into the internal jugular veins. These sinuses serve not only to carry into the jugular veins all the blood which is poured into the torcular, but likewise to receive blood from the lateral and posterior parts of the dura mater and cranium, from the inferior surface of the posterior lobes of the brain, and from the cerebellum. A short sinus, also of considerable width, is lodged in the tentorium cerebelli. This is the *straight sinus ;* it passes from before backwards, occupying about the middle of the vault of the tentorium, and opening behind into the torcular. It receives blood from the interior of the brain by two large veins, the *venæ magnæ Galeni*. The *cavernous sinuses,* two in number, lie one on each side of the sella Turcica, from which the internal carotid arteries separate them. Their irregular shape is rather that of reservoirs than of canals They receive the ophthalmic veins from the orbit, as well as numerous small veins from the cranial bones, the dura mater, and the anterior and middle lobes of the brain.

Other small sinuses are met with which serve chiefly to establish a communication between those above-mentioned, while at the same time they receive some blood from the neighbouring textures. The *petrosal* sinuses, two on each side, superior and inferior, pass between the cavernous and lateral sinuses: the *transverse* sinus runs between the petrosal and cavernous sinuses of opposite sides; and the *circular* or *coronary* sinus, while it receives blood from the pituitary body and from the sphenoid bone, connects together the cavernous sinuses in front, and thus completes the venous circle around the sella Turcica.

We see, in this arrangement of venous canals, a beautiful provision against the effects of undue venous congestion within the cranium, insured not merely by the inextensible nature of the principal venous canals, but also by the free anastomosis that exists between them, and by the numerous points at which they communicate with the veins of the cranium, and through these with the superficial veins of the scalp.

The spinal veins are extremely numerous and complicated. A very intricate venous plexus surrounds the dura mater on its lateral and posterior surfaces, embedded among the lobules of soft fat by which the exterior of that membrane is invested. This plexus, less intricate in the dorsal than in the cervical and lumbar regions, communicates very freely with a plexus of veins which surrounds the exterior of the vertebral laminæ and processes (the *dorsi-spinal veins* of Dupuytren). In front of the dura mater and situate between the outer edge of the posterior common vertebral ligament and the pedicles of the vertebræ, we find two remarkable venous sinuses which extend the whole length of the vertebral column from the occipital foramen to the sacrum. They are the *longitudinal spinal sinuses* of Willis. In calibre they present many inequalities, being dilated at one part and constricted at another, according to the number and size of the vessels which communicate immediately with them. The sinuses of opposite sides are parallel to each other, and communicate by transverse branches, which pass beneath the posterior common ligament. These transverse branches are of variable calibre, like the sinuses themselves, and are dilated at their middle; at which point they receive veins which emerge from the spongy texture of the bodies of the vertebræ (*basi-vertebral veins* of Breschet*). At the highest part of the vertebral canal, the spinal sinuses communicate with the internal jugular veins; in the neck, they communicate with the deep and superficial vertebral veins; with the intercostal veins in the dorsal region, and with the lumbar ones in the loins.

The *arachnoid* is the serous membrane of the cranio-spinal cavity. By its parietal layer it adheres to the dura mater, both of the cranium and spine, and by its visceral layer to the brain and spinal cord, with the intervention of the pia mater. The space between these two layers is the *arachnoid cavity*. In most regions, an interval exists between the visceral layer of the arachnoid and the pia mater, which is called the *sub-arachnoid cavity*. This space may be demonstrated by driving air or coloured liquid beneath the visceral layer of the arachnoid. In the spine the connexion of the arachnoid and pia mater is very loose, being effected by some long filaments

* See his very beautiful illustrations of the venous system.

of fibrous tissue, which interlace slightly, and are most abundant in the cervical region. Along the posterior surface of the spinal cord, in the middle line, the sub-arachnoid space is divided by means of a septum, which is probably only a modified portion of the tissue of the pia mater. This septum is most perfect in the dorsal region, but in the lumbar and cervical regions it is cribriform, and in some parts is very difficult of demonstration. Dr. Sharpey regards it as the reflection along the median line of a serous membrane, which he supposes to line the sub-arachnoid cavity. Did such a membrane exist, we should find an epithelium, which, however, we have sought for in vain.

The connexion of the arachnoid to the subjacent pia mater is not so loose in the head as in the spine. On the superior and lateral surfaces of the brain, where the convolutions are most prominent, the adhesion is very close, but opposite the sulci between the convolutions the pia mater recedes from the arachnoid and sinks to the bottom of each fissure, leaving large areolæ in which fluid may accumulate. Along the fissure of Sylvius, at the base of the brain, between the cerebellum and the posterior surface of the medulla oblongata, and between the posterior edge of the corpus callosum and the superior surface of the cerebellum, the arachnoid and pia mater are very loosely connected, so that at these situations spaces are found which are favourable for the accumulation of fluid.

The Cerebro-spinal Fluid.—This fluid, which fills the sub-arachnoid space during life, keeps the opposed surfaces of the arachnoid membrane in intimate contact. Its quantity, which varies between two and ten ounces, is in the inverse ratio of the bulk of the brain and spinal cord. Thus it is most abundant in old persons in whom these organs have shrunk, and it accumulates in cases of deficiency of any portion of them from malformation or disease. Its presence seems necessary to the healthy action of the nervous centres, for the removal of it in dogs by Majendie caused considerable disturbance of their functions, probably by favouring distension of the blood-vessels. It is, however, capable of being regenerated as quickly as the aqueous humour of the eye, and its reproduction restores the nervous centres to their natural state. When removed from the body a few moments after death, this fluid is, according to Majendie, remarkably limpid; it has a sickly odour and a saltish taste, and is alkaline, restoring the colour of reddened litmus.

The cerebro-spinal fluid is most probably secreted by the pia mater, since it is found wherever that membrane and sufficient space exist. The ventricles of the brain contain a secretion of very similar, if not identical characters, which Majendie describes as communicating with that of the sub-arachnoid space through an orifice at the inferior extremity of the fourth ventricle. This, however, is extremely doubtful, as the fluid of the ventricles is enclosed by a proper membrane which lines their cavity.

The cerebro-spinal fluid obviously affords mechanical protection to the nervous centres which it surrounds. The interposition of a fluid medium between them and the walls of the cavities is well adapted to guard the former against shocks communicated from without. Its accumulation at the base of the brain is highly favourable for the protection of the large vessels and nerves situate there.

The *pia mater* is the immediate investing membrane of the brain and spinal cord. It is composed of white fibrous tissue and blood-vessels. The former is most abundant in the pia mater of the cord, the latter are most numerous in that of the brain. The principal distinction, therefore, between the spinal and cerebral pia mater is as regards strength and thickness; the spinal being dense and strong, the cerebral being very delicate, almost wholly composed of minute blood-vessels, which are accompanied by white fibrous tissue in small quantity. The spinal membrane forms a complete sheath to the cord, and sends in processes which dip into its anterior and posterior median fissures. It is continuous with the neurilemma of the roots of the nerves on each side. At the inferior extremity of the cord it tapers and terminates in a thread-like process (*filum terminale*) which is inserted into the inferior extremity of the dura mater. Superiorly it gradually diminishes in density as it passes over the medulla oblongata to the cerebral and cerebellar hemispheres. To the surface of these it adheres closely, and innumerable minute blood-vessels pass from it into the nervous substance. It sinks into all the sulci and fissures, and passes into the lateral, the third and fourth ventricles. In the lateral and fourth ventricles it forms projecting processes or folds, somewhat fringed, highly vascular, and invested by epithelium derived from the membrane which lines the ventricles. These processes are called the *choroid plexuses.* Into the third ventricle, it sends a lamellar fold of triangular shape (*velum interpositum*), which forms a roof to that cavity and supports the fornix.

Attention has lately been directed to some minute sandy particles, globular in shape, which are frequently connected with the minute vascular ramifications of the internal pia mater. They are found chiefly in the choroid plexuses, and in that portion of the velum which invests the pineal gland. This sabulous matter is composed of phosphate of lime, with a small proportion of phosphate of magnesia, a trace of carbonate of lime, and a little animal matter.*

Of the Ligamentum dentatum.—This remarkable structure, found in the sub-arachnoid space, requires a brief notice. It seems to be a process of the pia mater, which exhibits more of the glistening appearance of white fibrous tissue than the rest of that membrane. It extends from the occipital foramen to the filiform termination of the pia mater, adhering by its inner straight border to that membrane, and attached on the other hand to the dura mater by a series of dentated processes which penetrate the visceral and parietal layers of arachnoid, pinning them, as it were, down to the fibrous membrane. They form a vertical septum between the anterior and posterior roots of the spinal nerves. The dentated processes vary in number from eighteen to twenty-two. The first is attached to the dura mater which covers the occipital foramen just behind the vertebral artery; the rest are inserted between the orifices for the exit of the spinal nerves, and the last is on a level with the first or second lumbar vertebra. A considerable quantity of yellow fibrous tissue exists in this structure, especially in its dentated processes.

The *Pacchionian glands* or bodies are whitish granules, composed of an albuminous material, which are found among the vessels of the pia mater, on the edges of the cerebral hemispheres, which push the arachnoid before them, and even project into the longitudinal sinus. They do not occur in the earliest periods of life, and are frequently absent even at the more advanced ages; but they are so often met with in the brains of adult and old persons that many anatomists regard them as normal structures.

Of the Spinal Cord.—The spinal cord is somewhat cylindrical in shape, slightly flattened on the anterior and posterior surfaces. Its anatomical limits are, the occipital plane above, and a point ranging in different subjects between the last dorsal and second lumbar vertebra below. It tapers to its exterior extremity, which lies concealed among the leash of nerves which comes off from its lumbar region, the *cauda equina*. Superiorly the spinal cord is separated from the medulla oblongata by the decussating fibres of the anterior pyramids.

In the cervical and lumbar regions the cord exhibits distinct swellings, of which the cervical is the larger. The cervical swelling extends from the third cervical to the third dorsal vertebra, the lumbar one commencing about the ninth or tenth dorsal vertebra,

* Van Ghert, de plexibus choroideis.

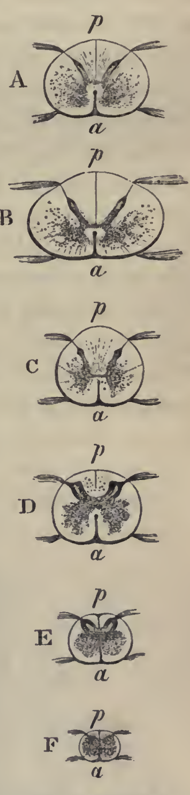
and not extending beyond the space corresponding to two vertebræ. These enlargements correspond to the situations at which the large nerves to the extremities emerge, in conformity with a law that the physical development of any portion of the cord is in the direct ratio of the sensitive and motor power of the parts which it supplies with nerves.

The spinal cord is divided along the median plane by an anterior and posterior fissure into two equal and symmetrical portions, of which one may be called the *right*, the other the *left* spinal cord. A transverse bilaminate partition, extending throughout the entire length of the cord, separates these fissures, and serves to unite its lateral portions. This partition is composed of a vesicular or gray and a white or fibrous lamina or *commissure,* the gray being situate posteriorly. When examined in a transverse section, the anterior fissure appears evidently wider but of less depth than the posterior; it is penetrated by a distinct fold of pia mater; its floor is formed by the white commissure, which has a cribriform appearance, from being perforated by numerous blood-vessels. The posterior fissure is much more delicate than the anterior, and about the middle of the cord its existence may be doubted; its depth, in the upper part of its course, is equal to fully one half of the thickness of the cord. A single, very delicate layer of pia mater enters it and penetrates to its floor, which is formed by the gray commissure.

On further examination of a transverse section of the cord, we observe that the interior of each half of it is occupied by vesicular matter, disposed somewhat in a crescentic form. The concavity of this crescent is directed outwards: its anterior extremity, or *horn,* is thick, but its margin has a dentated or stellate appearance, which is very distinct in some situations. The gray matter is prolonged backwards in the form of a narrow horn, which reaches quite the surface of the cord, near which it experiences a slight enlargement. This enlargement appears to consist of a gray matter, paler and softer than that of the remainder of the crescent, which has been distinguished by Rolando as *substantia cinerea gelatinosa,* surrounded by a layer of reddish-brown substance (see fig. 66, D, where the central part of the posterior horn is pale). An exact symmetry exists between the gray crescents of opposite sides, so that the description of one is applicable to the other.

The prolongation of the posterior horn of each gray crescent to the surface divides each half of the cord into two portions. All that is anterior to the posterior horn is called the *antero-lateral column:* and this comprehends the white matter forming the sides and front of that half of the cord, limited in front by the anterior fissure, and posteriorly by the posterior horn. The *posterior* column is situated behind the posterior horn of gray matter, and is separated from its fellow of the opposite side by the posterior fissure. The antero-lateral columns are united across the middle line by the anterior or white commissure; the gray crescents, by the posterior or gray commissure; while the posterior columns are not connected, except where the posterior fissure is imperfect or deficient.

Fig. 66.



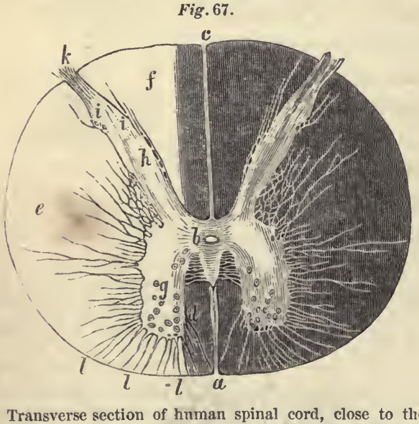
Transverse sections of the spinal cord:—A. Immediately below the decussation of the pyramids. B. At middle of cervical bulb. C. Midway between cervical and lumbar bulbs. D. Lumbar bulb. E. An inch lower. F. Very near the lower end. *a*. Anterior surface. *p*. Posterior surface. The points of emergence of the anterior and posterior roots of the nerves are also seen.

In the different regions of the cord great variety exists as regards the quantity of gray and white matter, and the disposition of the lateral portions of the former. There seems to be a much greater proportion of gray matter to white in the lumbar, than in the cervical or dorsal region of the cord. In the cervical region the crescentic portions are small, and the white matter is abundant. That portion of the white substance which is placed between the posterior gray horns, is augmented by the existence of two small columns (*posterior pyramids*), which extend from the medulla oblongata into this region. In the dorsal region the gray matter is at its minimum of development, and the white matter is likewise small in quantity. The diminution in the quantity of the latter appears more striking as effects the antero-lateral, than the posterior columns. In the lumbar region both the horns of the gray matter are manifestly thicker, and the stellate character of the anterior horn is well marked. Towards the inferior extremity of the cord the white matter appears gradually to cease, leaving the gray to form the principal constituent, until, in the commencement of the filiform process, it is found alone (fig. 66).

The roots of the spinal nerves emerge from the cord on each side along two lines which are separated by the ligamentum dentatum. The posterior line corresponds to the margin of the posterior horn of gray matter, the anterior one is placed about midway between it and the anterior fissure. When the roots of the nerves have been carefully removed, their points of emergence are indicated by two series of foramina in linear sequence on each side; but there is no appearance of fissures in those situations. The roots of the nerves penetrate the substance of the cord, and are chiefly, if not entirely, connected with the antero-lateral columns.

The fibrous matter of the cord consists of some fibres which pass in a longitudinal direction, which are chiefly superficial or contained in the posterior columns, and of others which are oblique or transverse, and are found in the antero-lateral columns, or in the white commissure, which is wholly composed of such fibres. Among the elements of the gray matter fibres are found in great numbers, the direction of which is probably for the most part oblique or transverse, as considerable portions of them may be seen so running, when a piece of gray matter, cut transversely, is examined under the microscope. The gray matter of the cord is disposed in two longitudinal columns, the shape of which in the several regions of the cord is represented in the above transverse sections (fig. 66). These columns extend from the lower part of the medulla oblongata, with the gray matter of which they are continuous. The aspect of their surfaces is outwards and inwards. That which looks inwards is convex, and is united to the corresponding surface of the opposite side by the gray commissure, which is a vertical plane, with surfaces looking directly forwards and backwards. At the inferior extremity of the cord these columns gradually taper to a point, and coalesce as the white matter diminishes.

Fig. 67.



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

Caudate and spherical vesicles, imbedded in their usual granular matrix, exist in the gray matter of the cord at all situations, in the horns as well as in the commissure. The caudate vesicles are most numerous and distinct in the anterior horn, and at the root of the posterior one. The rest of the posterior horn and the gelatinous substance resemble very closely in structure the gray matter of the convolutions of the brain. When very thin transverse sections are examined with low powers, a good general view of the relative disposition of the gray and white *columns* is obtained, but we gain no satisfactory information as regards the relation of the *elements* of these columns (fig. 67). Stilling and Wallach's plates accord generally with the results of our own examinations; but we cannot admit the accuracy of their interpretation of some of the appearances which they have witnessed and delineated.

In such a section as that just described, the distinction of gray and white matter is very obvious. From the surface of each horn of the former several lines, of the same colour and general appearance as the central mass, pass, in a radiating manner, towards the surface of the cord and to the surface of the fissures (fig. 67). These lines, according to Stilling and Wallach, are continuous with the roots of the nerves, and are nerve-tubes proceeding from the gray matter to form these roots. Their existence, however, in sections made in situations intermediate to the points of emergence of the nerves, shews that this explanation cannot be the true one. Moreover, they radiate over a surface much more extensive than that from which the roots take their rise, and several pass to that part of the surface of the cord which bounds the fissures, and from which it is impossible that they could reach the point of emergence of either root to contribute to its formation. It is not improbable, however, that they may be processes of the gray matter prolonged toward the surface, to which blood-vessels may pass from the pia mater.*

We observe in the gray matter numerous nerve-tubes of various size passing among its elements in different directions. Besides these, the branching processes from the caudate vesicles are found here: these processes differ from the nerve-tubes in the absence of the white substance of Schwann, in their grayish colour, in their branching, and in a certain minutely granular texture. Numerous extremely minute fibres, perfectly transparent in texture, may be traced to be continuous with the finer subdivisions of these processes (fig. 56, p. 214). Fibres of the same appearance are occasionally found among the tubes of the white substance of the spinal cord; their connexion with those of the gray matter is unknown.

Capillary blood-vessels are met with in great numbers ramifying in the gray matter. They are much more numerous in this than

* Mr. Smee has lately exhibited to us some well-injected preparations, in which these lines are shewn to contain vessels.

in the white matter, and the observer should be careful not to confound the most minute of them with some of the fibrous elements above described.

So far as our present knowledge of the minute anatomy of the spinal cord extends, it is favourable to the supposition that the spinal nerves derive their origin, at least partly, from the gray matter. The longitudinal fibres of the cord may consist in part of fibres continuous with those of the brain or cerebellum, and in part of commissural fibres, serving to unite various segments of the cord with each other, or to connect some part or parts of the encephalon with them. Those fibres which may be regarded as strictly spinal are probably oblique in their course, forming their connexion with gray matter at a point higher up in the cord than that at which they emerge from its surface, and may be readily confounded with the longitudinal fibres when their course is long. Other oblique or transverse fibres probably do not emerge from the cord, but connect the segments of opposite sides, forming a transverse commissure. So that four classes of fibres, each different in function, may be considered to exist in the cord. 1. *Spinal fibres*, oblique or transverse, which propagate nervous power to or from the segments of the cord itself. 2. *Encephalic fibres,* longitudinal, the paths of volition and sensation, which connect the spinal cord with the various segments of the encephalon. 3. *Longitudinal commissural fibres.* 4. *Transverse commissural fibres.*

Of the Encephalon.—The brain or encephalon is the mass which is contained within the cranial cavity. The plane of the occipital foramen separates it from the spinal cord, inasmuch as that plane would about pass through the inferior extremity of the medulla oblongata.

Four segments are obviously distinguished in the encephalon. 1. The *medulla oblongata.* 2. The *cerebrum.* 3. The *cerebellum.* Some fibres of the medulla oblongata extend to the cerebrum, and some to the cerebellum. The fourth segment, which is called the *mesocephale,* contains fibres passing between all the rest, as well as some connecting opposite sides. This constitutes a sort of conflux to the segments above named, and may be compared to a railway terminus, at which several lines meet and pass each other.

The brain of the adult man weighs about 50 oz. or a little more than 3 lbs. avoirdupois.* This great weight depends mainly

* See Reid's Tables. Lond. and Edinb. Monthly Journal of Med. Science. Ap. 1843.

upon the cerebrum and cerebellum, the medulla oblongata and mesocephale forming not more than one-tenth of the whole weight. These parts exist in their highest state of development in man. Their size does not appear to be regulated by the physical development of the body, either in man or in the lower animals. Thus the horse, although greatly exceeding the human subject in the size of his body, has a brain considerably inferior. The largest brain of a horse weighs, according to Sœmmering, 1 lb. 7 oz , but the smallest adult human brain may be estimated at 2 lbs. 5½ oz. Many other instances might be cited, of animals of great bulk, with brains weighing considerably less than that of man. The brains of the elephant and the whale, however, although inferior to it in general organization, are absolutely heavier than that of man. That of an elephant, dissected by Sir Astley Cooper, had a weight of 8 lbs. 1 oz. ; and Rudolphi found the brain of a whale, 75 feet long, (*Balæna mysticetus,*) to weigh 5 lbs. 10¼ oz. Yet how inferior must be the development of the brain in these stupendous animals relatively to the whole body, if, with their enormous superiority of bulk, their brains exhibit so little excess of weight over that of man !

Even among men there does not appear to be any fixed relation between the bulk of the body and that of the brain. A large man has by no means necessarily a large brain, and it oftens happens that persons of small stature have the brain above the average size. In women the brain is generally lighter than in men. Dr. John Reid assigns an average difference of 5 oz. 11 dr.. in favour of the male brain. Yet this difference is scarcely proportionate to the general inferiority of organization and of size of the female to the male.

It is impossible to explain the great superiority of the human brain, both in organization and in the absolute quantity of nervous matter which it contains, without admitting its connexion with the mind, and the influence exerted upon its nutrition and growth by that immaterial principle. The men of greatest intellectual power are those who possess the largest brains. Cuvier's brain, as stated by Tiedemann, weighed 4 lbs. 11 oz. 4 dr. 30 grs. troy; and that of Dupuytren 1 oz. 4 dr. 30 grs. less. On the other hand, the brain of an idiot weighs scarcely more than that of the horse mentioned above. Tiedemann found the brain of an idiot, fifty years old, to weigh 1 lb. 8 oz. 4 drs.; and that of another, forty years old, 1 lb. 11 oz. 4 drs. In advanced age, when the mental faculties have declined, the brain generally experiences a decrease of size; there are many however, who preserve their intellectual vigour to a very advanced period of life, and in such persons, doubtless, the brain does not exhibit any evidence of shrinking. It is during the period of greatest mental activity and power that the brain acquires and maintains its highest point of development, that is, between the ages of twenty and sixty.

Whilst there is an evident connexion between a large *quantity* of cerebral matter, and a highly developed intellect, the *quality* of the mind and that of the brain substance may also be supposed to have a close relation to each other. For great power of action a *large* muscle is needed, but for vigorous and well-adjusted muscular movement a certain *quality* of fibre is also necessary to give full scope to the nervous power (see pp. 185—8—90). It is impossible to determine what this peculiarity in quality is, but some idea of the great influence which it may possess in the exercise of the two great vital forces, the *muscular* and *nervous,* may be gained from comparing the energy and action of a well-bred horse with those of one which, in the language of the turf, shews little or no breeding. The actual amount of muscular or nervous fibre may be the same in both, or it may be less in the horse of good breeding than in the other, yet the former does his work and endures fatigue better.

The nature of the connexion between the mind and nervous matter has ever been, and must continue to be, the deepest mystery in physiology; and they who study the laws of Nature, as ordinances of God, will regard it as one of those secrets of His counsels "which angels desire to look into."* The individual experience of every thoughtful person, in addition to the inferences deducible from revealed Truth, affords convincing evidence that the mind can work apart from matter, and we have many proofs to shew that the neglect of mental cultivation may lead to an impaired state of cerebral nutrition; or on the other hand, that diseased action of the brain may injure or destroy the powers of the mind. These are fundamental truths of vast importance to the student of mental *pathology* as well as of physiology. It may be readily understood that mental and physical development should go hand in hand together, and mutually assist each other; but we are not, therefore, authorized to conclude that mental action results from the physical working of the brain. The strings of the harp, set in motion by a skilful performer, will produce

* The admirable chapter in Bp. Butler's Analogy, "Of a Future Life," cannot be too attentively studied in reference to this subject.

harmonious music if they have been previously duly attuned. But if the instrument be out of order, although the player strike the same notes, and evince equal skill in the movements of his fingers, nothing but the harshest discord will ensue. As, then, sweet melody results from skilful playing on a well-tuned instrument of good construction, so a sound mind, and a brain of good development and quality, are the necessary conditions of healthy and vigorous mental action.

Medulla Oblongata.— Of the segments of the encephalon above enumerated, the medulla oblongata is that which is more immediately connected with the spinal cord, and through which the brain is brought into communication with the other vital organs and with most of the peripheral parts. It is, therefore, truly "the link which binds us to life." In form and general anatomical characters, it very much resembles the spinal cord, with which it is continuous, standing in the same relation to it, as the capital to the shaft of a column.

In the sense in which we here speak of it, the medulla oblongata is limited above by the mesocephale; but its constituent fibres extend beyond that segment, and form important connexions with the rest of the brain. It is completely contained within the cranial cavity, its lowest part being just above the level of the plane of the occipital foramen.

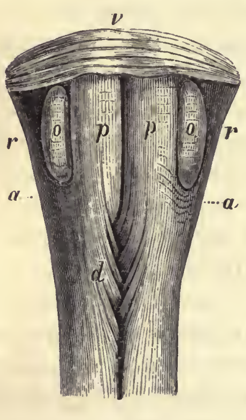
The size of the medulla oblongata is in the direct ratio of that of the nerves which proceed from it. Hence it is very much larger, both absolutely and relatively, in some of the lower animals than in man: in many of them it forms the largest of all the segments of the encephalon, while in man it is much the smallest.

In the medulla oblongata there is the same symmetry of arrangement which we have noticed in the cord. An anterior and posterior fissure divide it into two equal and symmetrical portions. The posterior fissure is deep and narrow, and is continuous with that of the cord. The anterior fissure is wider and less deep, and separated from the same fissure of the cord by certain fibres which cross obliquely from each side in its lower third, decussating each other. These fibres are called the *decussating fibres* of the anterior *pyramids*, and form, very fitly, an anatomical demarcation between the medulla oblongata and the spinal cord.

The floor of the anterior fissure is formed by a layer of fibrous matter which is rendered cribriform by the orifices of the numerous blood-vessels which penetrate it. This constitutes a commissure of transverse fibres, similar to that described in the spinal cord. The posterior fissure extends to the posterior surface of this commissure, there being no such transverse lamina of vesicular matter in the medulla as in the cord.

When the pia mater has been carefully removed from the surface of the medulla oblongata, certain grooves are seen which indicate a subdivision of the organ, which is convenient for the purposes of description. In front are the *anterior pyramids* (*corpora pyramidalia antica*) separated from each other along the middle line by the anterior fissure. External to each anterior pyramid there is an oval prominence surrounded by a superficial groove, which in some instances is partially interrupted by some *arciform fibres* which cross it at its lower part. These projections are the *olivary bodies.* External to these, and forming the lateral and a great part of the posterior region of the medulla oblongata, are the *restiform bodies,* two thick columns of fibrous matter, which are separated from each other along the middle line by two slender columns, *the posterior pyramids.* These last bound the posterior fissure.

Fig. 68.



Front view of the medulla oblongata:—*p, p.* Pyramidal bodies, decussating at *d.* *o. o.* Olivary bodies. *r, r.* Restiform bodies. *a, a.* Arciform fibres. *v.* Lower fibres of the Pons. Varolii.

The *anterior pyramids* are bundles of fibrous matter which extend between the antero-lateral columns of the cord and the cerebral hemispheres. Below the mesocephale the fibres are compactly applied to each other so as to form on each side of the median line a column of white matter, the transverse section of which has more or less of a triangular outline. Traced upwards, the pyramids are found to pass into the mesocephale above its inferior layer of transverse fibres, the *pons Varolii.* At its entrance into this part of the brain each pyramid experiences a slight but well-marked constriction, but immediately expands again; and its fibres in their further course upwards gradually diverge, and contribute to form the inferior lamina of the crus cerebri.

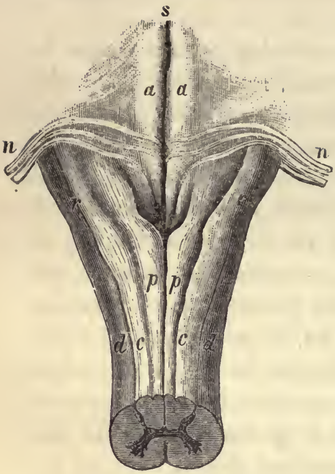
In their ascent through the mesocephale the fibres of the pyramids are crossed at right angles by some deep transverse fibres on different planes which belong to the same system as those which constitute the pons. With these fibres those of the pyramids interlace. Vesicular matter is deposited in the intervals between the more deeply seated fibres, from which probably some fibres take their origin, and join the pyramids at their emergence from the pons, to form the inferior layers of the crus cerebri.

Traced downwards, the fibres of each anterior pyramid pass in greater part *backwards* as well as downwards, sinking into the antero-lateral column of the cord of the opposite side (fig. 68, *d*), whilst a small portion of them, those, namely, which constitute the outer margin of each pyramid, pass to the column of the same side. Other fibres of these bodies do not pass down into the spinal cord at all, but taking a curved course around the inferior extremity of each olivary body they ascend towards the cerebellum, forming the *arciform* fibres. Or, if the description be pursued in an opposite direction, each pyramid may be stated to be composed of some fibres from the antero-lateral spinal column of its own side, and of others which greatly exceed the latter in number, from the antero-lateral column of the opposite side, and it is connected with the restiform body of the same side by the arciform fibres.

The decussation takes place by from three to five bundles of fibres from each pyramidal body. In separating the margins of the anterior fissure, these fibres are found to interrupt its continuity with the anterior fissure of the medulla oblongata, and, therefore, may be conveniently referred to as a boundary between the medulla oblongata and the spinal cord.

This decussation has great interest in reference to the explanation of the phenomena of diseased brain. It is well known that lesion of one hemisphere of the brain, when sufficiently extensive to cause paralysis, will induce that paralysis on the opposite side of the body. And, although a very few exceptions have been recorded, this is so constant that it must be regarded as a law, that the influence of each hemisphere is rather upon the opposite half of the body than on that of its own side. It is not, however, meant that the hemisphere has *no* influence on the same side of the body. On the contrary, it is most probable that it does exert some influence from the partial connexion of each anterior pyramid with the antero-lateral column of the spinal cord on the same side. Now the decussation, above described, obviously suggests an explanation of this phenomenon, which is among the most interesting that anatomy can offer. In confirmation of this statement it may be remarked, that lesion of one side of the cord, *below* the decussation, affects the same side of the body, and that alone; whilst disease of a paralysing influence, wherever it occurs *above* the decussation, affects the opposite half of the body. The exceptions to this rule are too anomalous and few to invalidate the explanation so long adopted.

Fig. 69.



Posterior view of the medulla oblongata:—*pp*. Posterior pyramids, separated by the posterior fissure. *rr*. Restiform bodies, composed of *cc*, posterior columns, and *dd*, lateral part of the antero-lateral columns of the cord. *aa*. Olivary columns, as seen on the floor of the fourth ventricle, separated by *s*, the median fissure, and crossed by some fibres of origin of *nn*, the seventh pair of nerves.

The restiform bodies form the lateral and posterior part of the medulla oblongata. They are cylindrical in form. Below they are distinctly continuous with the antero-lateral and posterior columns of the cord. As they ascend, they diverge and leave a considerable space between them, which is the fourth ventricle. Each restiform body passes into the corresponding hemisphere of the cerebellum, forming a considerable portion of the crus, the stalk of fibrous matter around which the hemisphere is formed. These bodies are, therefore, the bond of connexion between the cerebellum and the spinal cord, for which reason they have been appropriately designated *processus cerebelli ad medullam oblongatum.*

The posterior median fissure is bounded on each side by a small column, not exceeding one-eighth of an inch in breadth. These columns are called the *posterior pyramidal bodies.* Their outer limit and line of demarcation from the restiform bodies is indicated by a superficial groove, along which a separation of the two structures readily takes place, in a preparation previously hardened in spirit.

The *olivary bodies* are oval projections on each side of the anterior pyramids. When the latter have been carefully removed, it may be demonstrated that these bodies are continuous with the central part of the medulla oblongata. They are coated on the outside with fibrous matter, within which is a folded lamella or capsule of vesicular substance, enclosing a white nucleus. By slicing off a layer of this body even with the surface of the medulla, the capsule may be seen disposed as a wavy line, surrounding an oval space of white matter. If examined in transverse section, this wavy line of vesicular matter is still apparent, but it is incomplete behind and within; and the same may be observed on a vertical section of the olivary body. This lamina is called the *corpus dentatum.*

When the pyramids are very largely developed, these oval projections on the surface of the medulla oblongata do not appear.

Hence the olivary eminences are peculiar to the human subject, and some of the monkeys.

On tracing the olivary bodies downwards, they are found to approximate towards each other, the anterior pyramids which separate them gradually diminishing in breadth, and they apparently terminate by becoming continuous with the antero-lateral columns of the spinal cord.

The olivary bodies, though separated from the margin of the pons Varolii by a distinct depression, may be traced upwards through the mesocephale along with the central substance of the medulla oblongata (*fasciculi innominati* of Cruveilhier), forming a considerable portion of the superior layer of each crus cerebri, and apparently becoming continuous with the optic thalamus and quadrigeminal bodies.

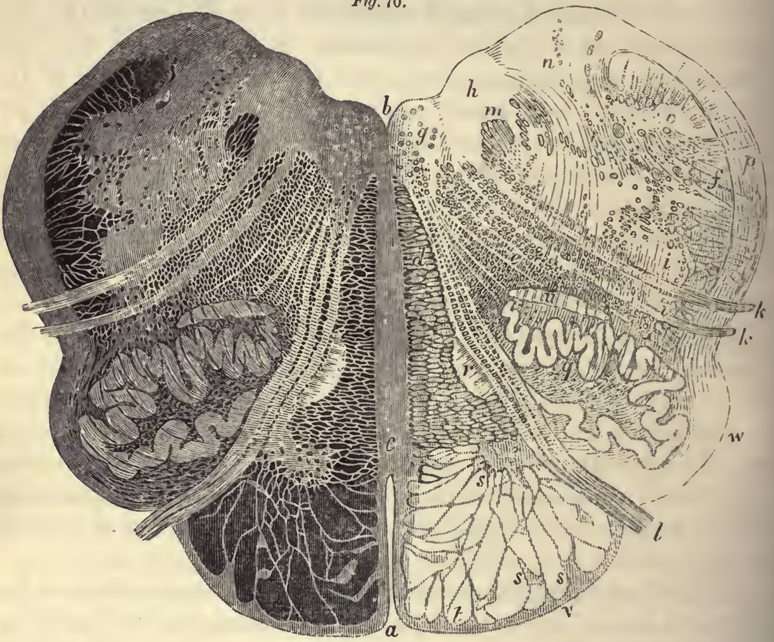
The olivary bodies and the central substance of the medulla oblongata may be described as connecting the spinal cord with the quadrigeminal bodies and the optic thalami.

It seems highly probable, that the olivary bodies constitute the essential portion or *nucleus* of the medulla oblongata; that on which its power as an independent centre depends. Strong support to this view is derived from the important fact, that these bodies and the central portion of the medulla oblongata, with which they are directly continuous, contain that intermixture of vesicular and fibrous matter which constitutes the main character of a nervous centre.

If this be correct, the anterior and posterior pyramids, and the restiform bodies, must be regarded as consisting chiefly of fibres which pass from the spinal cord to the cerebrum, or cerebellum, and not essentially concerned in the formation of the medulla oblongata. The fibres of these bodies are in fact mainly commissural; the anterior pyramids serving to connect the cerebral hemispheres to the spinal cord, the restiform bodies connecting the cerebellum to it, and the posterior pyramids being the means of connexion posteriorly between the medulla oblongata and the cervical and dorsal regions of the spinal cord. But the olivary bodies and the central matter of the medulla are directly continuous with certain principal gangliform masses of the brain, the optic thalami and quadrigeminal bodies, and by their prolongation upwards form a large portion of the crura of the brain.

From the description of the minute structure of the medulla oblongata by Stilling, founded upon investigations conducted in the same way as those on the spinal cord, it would appear that numerous transverse fibres pass into the central and posterior part of the medulla. It is not unlikely that many of these so called fibres *may be* bundles of nerve tubes, but it is also highly probable that many of them are bloodvessels, which pass in great numbers into the central substance of the medulla. The same mode of connexion which exists between the roots of the nerves and the

Fig. 70.



Transverse section of the medulla oblongata through the lower third of the olivary bodies. (From Stilling.) Magnified 4 diameters.

a. Anterior fissure. *b.* Fissure of the calamus scriptorius. *c.* Raphé. *d.* Anterior columns. *e.* Lateral columns. *f.* Posterior columns. *g.* Nucleus of the hypoglossal nerve, containing large vesicles. *h.* Nucleus of the vagus nerve. *i, i.* Gelatinous substance. *k, k.* Roots of the vagus nerve. *l.* Roots of the hypoglossal, or ninth nerve. *m.* A thick bundle of white longitudinal fibres connected with the root of the vagus. *n.* Soft column (*Zartstrang*, Stilling). *o.* Wedge-like column (*Keelstrang*, Stilling). *p.* Transverse and arciform fibres. *q.* Nucleus of the olivary bodies. *r.* The large nucleus of the pyramid. *s, s, s.* The small nuclei of the pyramid. *u.* A mass of gray substance near the nucleus of the olives (*Oliven-Nebenkern*). *u, q, r,* are traversed by numerous fibres passing in a transverse semicircular direction. *v, w.* Arciform fibres. *x.* Gray fibres.

spinal cord, whatever that may be, will no doubt be found to prevail in the medulla; and as several important nerves emerge from this portion of the encephalon, it seems very likely that their fibres should penetrate to its central part to form a connexion with its gray matter. This question, however, is not to be decided by the use of low powers of the microscope, such as Stilling employs; nor have our trials with higher ones as yet led to any information sufficiently specific to enable us to make a positive statement respecting the points in question. There is nothing in the results of Stilling's researches which does not confirm that which previous dissections, by coarser means of observation, had pointed out — namely, that the restiform and pyramidal bodies are composed in great part of fibres, taking a longitudinal course, while the central portion contains both the vesicular and fibrous nervous elements. The fibres of the latter, according to Stilling, taking chiefly, if not exclusively, a transverse direction.

There is no evidence of any interchange of fibres between the restiform bodies, nor between the posterior pyramids of the right and left sides, such as has been noticed between the anterior pyramids in the description of their decussating fibres. The central or olivary columns of the medulla oblongata, however, have a very intimate connexion with each other, along the mesial plane, apparently by fibres passing from one to the other.

When the medulla oblongata is divided vertically along the median plane, a series of fibres is seen to form a septum between its right and left half. These fibres take a direction from before backwards, and appear to connect themselves with the posterior olivary columns. They are limited inferiorly by the decussating fibres. Cruveilhier proposes for them the name *antero-posterior fibres*; they appear to belong to the same system as the arciform fibres.

Of the Cerebellum.— This segment of the encephalon is situated above and behind the medulla oblongata in a distinct compartment of the cranium, which has for its roof the tentorium cerebelli. It bears to the cerebrum in point of weight about the proportion 1 : 8, and to the entire encephalon, 1 : 10.

The cerebellum consists of a central and of two lateral portions. The former, also called the *median lobe*, is the primary part; it is the only part of the organ which exists in fishes and reptiles; the lateral portions or *hemispheres* are additions to this, and denote an advance in development. It is in birds that these are first found; they are most highly developed in mammals, and attain their maximum in man.

Upon removing the pia mater from the surface of the cerebellum, we observe its arrangement in numerous thin lamellæ, which are attached to a central column of fibrous matter. A vertical section of either hemispheres serves well to display their structure. A series of planes of fibrous matter become detached from the central white column, each plane separating from it at a different angle. These planes are in number about ten, counting those on the upper as well as the under surface. Those situated in front are detached at a right angle, the posterior ones at an acute angle. Each plane forms the centre of a lobule, and as it proceeds outwards secondary planes are detached from it, and from these again others separate. These secondary and tertiary planes are clothed by a layer of vesicular matter, which also invests the primary planes at the angles of separation from the principal central column.

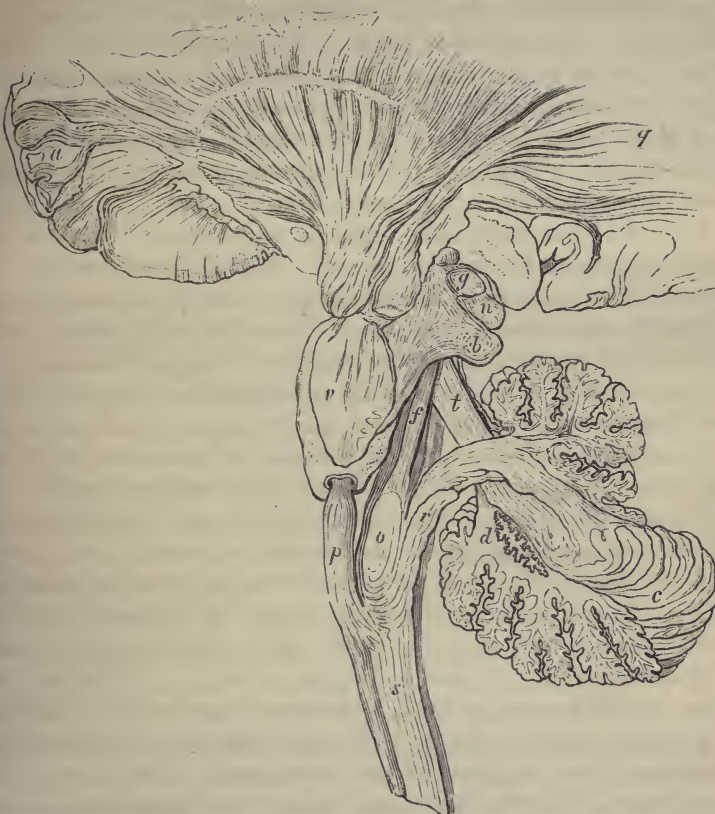
We have described each primary plane as forming the central portion, or stem of a lobule. Each lobule is circumscribed and separated from those in immediate relation to it, by a fissure which extends to the principal column. The lobules are composed of laminæ which derive their fibrous matter from the central stem.

Thus the substance of each hemisphere of the cerebellum is penetrated by a number of fissures, easily traced by following the pia mater, which lines them. These fissures are divisible into two classes, primary and secondary. The primary penetrate to the principal central column, and isolate the lobules; the secondary separate the lamellæ of which each lobule is composed. The deepest and most remarkable of the former corresponds to the posterior margin of each hemisphere, passing in the horizontal plane forwards, and separating the posterior laminæ into a superior and inferior set.

The structure of the median lobe is essentially the same as that of the hemispheres. A stem of fibrous matter, continuous with the *processus cerebelli ad testes,* constitutes the central column, and planes radiate from it in the same manner as in the hemispheres. Lobules are formed around these planes, and the aggregate of those on the superior surface of the median lobe constitutes what is called the *superior vermiform process;* and that of the inferior ones, the *inferior vermiform process.* The lobules of the median lobe have a distinct continuity of substance with those of the hemispheres on each side, and thus the entire lobe becomes a medium of connexion, or a commissure between the hemispheres; nevertheless, the similarity of its structure to that of the hemispheres, and its existence in the animal series without the lateral portions, denote that it exercises an independent function.

Within the central stem of each hemisphere of the cerebellum, the fibrous matter is partially interrupted by a peculiar arrangement of the vesicular substance, called by Vicq d'Azyr *corpus dentatum* (fig. 71, *d*). This is only found in the inner half of the stem, at about a quarter of an inch from the origin of the crus. It may be

Fig. 71.



Analytical diagram of the encephalon—in a vertical section. (After Mayo.)
s. Spinal cord. *r.* Restiform bodies passing to, *c*, the cerebellum. *d.* Corpus dentatum of the cerebellum. *o.* Olivary body. *f.* Columns continuous with the olivary bodies and central part of the medulla oblongata, and ascending to the tubercular quadrigemina and optic thalami. *p.* Anterior pyramids. *v.* Pons Varolii. *n*, *b*. Tubercula quadrigemina. *g.* Geniculate body of the optic thalamus. *t.* Processus cerebelli ad testes. *a.* Anterior lobe of the brain. *q.* Posterior lobe of the brain.

demonstrated by making a vertical section through the cerebellar hemisphere, leaving two-thirds of its substance to the outside of the section. The surface of the section presents at the situation above described a remarkable layer or capsule of gray matter, surrounding in great part an oval space; the gray layer has an undulating disposition, and is convex towards the surface; but open towards the crus. The precise object of this remarkable structure is not known; but the microscopic investigation of it shews that in it there is a mingling of the elements of the vesicular and fibrous substances.

The central stem, or crus, around which each hemisphere of the cerebellum is developed, is formed by three bundles of fibres, each on a different plane. These are called its peduncles. Through them the cerebellum forms a connexion with other parts of the encephalon. The superior layer or peduncle is a bundle of fibres which extends to the corpora quadrigemina, *processus cerebelli ad testes ;* the middle layer passes to the medulla oblongata, the *restiform bodies ;* and the inferior peduncle consists of transverse fibres, (*Pons Varolii*), which pass to the opposite side, and also form a considerable portion of the mesocephale.

Lesions of the cerebellum, when so deep-seated as to affect the primary planes of fibrous matter or the central stem, have the same crossed effect as those of the cerebrum. This is not so obviously explicable as the similar instance of the cerebrum, for the cerebellar fibres of the medulla oblongata (restiform bodies) do not appear to decussate. Yet it seems scarcely necessary, in order to explain the phenomenon, to have recourse to the supposition that they do decussate. The close connexion between the restiform bodies and the pyramids, by means of the arciform fibres, renders the latter exceedingly liable to sympathise with the condition of the former, and, therefore, prone to propagate the morbid influence to the opposite half of the spinal cord, and through that to the opposite half of the body. It must be borne in mind that some of the fibres of the anterior pyramids very probably derive their origin from the central gray matter of the medulla oblongata, as well as of the mesocephale, and that some, at least, of those which affect the right half of the cord, probably derive their origin from the left side of either or both of those segments of the encephalon. That lesion of one hemisphere of the cerebellum may influence the corresponding half of the medulla oblongata, is likely, from the connexion which the restiform fibres establish between them. The connexion of the cerebellum with the mesocephale is most clearly established by means of the transverse fibres which constitute the *Pons Varolii.*

Respecting the intimate structure of the cerebellum, little is known of a very exact nature. The white stems and plates are fibrous, and consist of multitudes of nerve-tubes of all sizes, which follow the general direction of each stem or plate. These fibres doubtless tend principally to propagate the peculiar influence of the cerebellum to the spinal cord and the mesocephale. Some probably are commissural, as the processus cerebelli ad testes (or cerebro-cerebellar commissures), the fibres of the pons, and some of those of the median lobe. Mr. Mayo supposes that others pass between the laminæ, but their existence is extremely doubtful.

The vesicular matter which covers the plates contains the ordinary elements, of which, however, the caudate vesicles constitute a principal portion (p. 213). These are so disposed that their processes pass off chiefly towards the circumference, their obtuse extremities being directed towards the laminæ. Besides these, there is in each layer of vesicular matter a thin lamina composed of round clear nucleus-like particles, which cohere to each other without the intervention of any matrix or other connecting substance. Fine nerve-tubes and blood-vessels pass through it. This lamina is intermediate to two which contain nerve-vesicles one of which is in immediate connexion with the fibrous matter of the cerebellum, the other with the pia mater.

Of the fourth Ventricle.—The divergence of the restiform bodies in their ascent to the hemispheres of the cerebellum leaves a considerable space, which is of a lozenge shape, having its superior angle towards the brain, its lateral angles towards the cerebellar hemispheres, and its inferior angle at the point of separation of the restiform bodies. Along its floor are seen the central or olivary columns of the medulla oblongata, extending upwards to the optic thalami. A fissure, continuous with the posterior median fissure, separates these columns. Some bundles of white fibres, which may be traced to the soft portion of the seventh pair of nerves, cross these bundles nearly at right angles to them and to the fissure (p. 266), and form with the latter the *calamus scriptorius,* the white fibres constituting the barbs of the pen. The roof of this ventricle is formed in front by the anterior laminæ of the superior vermiform process, which constitute the *valve of Vieussens;* and behind by the inferior vermiform process. A process of pia mater enters it at its inferior angle, just as the choroid plexus penetrates the inferior cornu of the lateral ventricles of the brain. The reflexion of the lining membrane on the process of pia mater seems to close up the ventricle below, and cut off its direct communication with the subarachnoid space. A canal, which passes through the mesocephale, establishes the communication of this with the third ventricle, *iter a tertio ad quartum ventriculum.*

The fourth ventricle properly belongs to the medulla oblongata. It is, therefore, present in all the vertebrate classes, and is, in point of size, directly proportionate to the medulla itself.

Of the Mesocephale.—This term, suggested by Chaussier, denotes that this portion of encephalon is the bond of union to the rest, the cerebrum above, the medulla oblongata below, and the cerebellum behind.

The inferior surface of the mesocephale, the *pons Varolii,* consists of a series of curved fibres, which pass from one crus cerebelli to the other. When the brain lies with its base uppermost, these fibres appear to cross over the upward continuations of the anterior pyramids, as a bridge over a stream. Hence the term *pons* was applied to them by Varolius.* The fibres form a series of curves, convex forwards, concave towards the medulla oblongata, the posterior being much less curved than the anterior. At either side they become more closely packed, taper, and form the inferior layer of each crus cerebelli. Along the middle line a groove traverses the surface of the pons from its posterior to its anterior margin, in which the basilar artery usually lies.

The fibres of the pons are always developed in the direct ratio of the hemispheres of the cerebellum. In animals which have only the median lobe, there is no pons; and when the hemispheres are small, the pons is small likewise. Hence these fibres must be regarded as especially belonging to the cerebellum, and as serving, whatever other office they may perform, to connect the hemispheres of opposite sides. They constitute, therefore, *the great transverse commissure of the cerebellum*, and are to the hemispheres of that organ what the corpus callosum is to those of the brain.

These transverse fibres do not form merely a superficial plane, which covers the pyramids in their upward passage: on the contrary, they extend to more than one half of the depth of the mesocephale, as is apparent on a transverse section of it. The more superficial fibres simply cross from one side to the other; the deeper-seated ones interlace with those of the pyramids. The fibres are irregularly disposed in planes, and vesicular matter is interposed between the more deeply-seated ones. From this gray matter it is not improbable that some of the fibres of the pyramids may take origin.

On the superior surface of the mesocephale are the quadrigeminal bodies (*nates* and *testes*), and beneath these the olivary columns. A slight longitudinal groove separates the quadrigeminal bodies into a right and left pair, and a transverse groove indicates their division into an anterior and posterior pair. They are gangliform bodies, of a grayish white colour, containing fibrous and vesicular matter. The anterior (*nates*) are somewhat elliptical in shape; they are the larger in man. The posterior (*testes*) are hemispherical, and somewhat lighter in colour. These bodies are much more developed in the lower animals than in man. In mammalia

* The terms *annular protuberance, isthmus encephali, nodus encephali,* are also frequently used.

only do they exist as four. In birds, reptiles, and fishes, they are only two in number, and are called *optic lobes*, from their connexion with the optic nerves. They are hollow in these classes, but in mammalia they are solid.

Between each testis and the corresponding hemisphere of the cerebellum, a band of fibrous matter extends—*processus cerebelli ad testem.* Each band may be traced into the crus cerebelli of the same side, of which it forms the superior layer, so that its fibres are doubtless continuous with some of those which form the white plates of the median and lateral lobes. The connexion of these processes with the testes is more apparent than real. They seem rather to pass beneath them to the optic thalami; and, therefore, it has been justly remarked, they might be more appropriately named *processus cerebelli ad cerebrum.* The valve of Vieussens occupies the interval between these processes. This layer evidently results from the spreading out of some of the anterior lamellæ of the superior vermiform process.

From the preceding description it will appear, as before stated, that the stem of fibrous matter which forms the crus cerebelli derives its fibres from, or is continuous with, three planes of fibrous matter: the highest, or most superficial, being the processus cerebelli ad testem; the second, or middle, the restiform body; and the inferior the fibres of the pons. By the first, the cerebellum and cerebrum are connected; by the second the cerebellum is connected with the medulla oblongata; and by the third, each hemisphere is brought into union with its fellow, and with the mesocephale. Foville assigns other fibres as constituents of the crura cerebelli, which he describes as expansions connected with the fifth and auditory nerves.

The crura cerebelli seem to emerge from the posterior angles of the mesocephale. From its anterior part there proceed upwards, with a slight divergence, two similar processes, of considerable thickness, which enter each hemisphere of the brain, and upon which each of those masses rests, as a mushroom upon its stalk.

A septum of a similar kind to that described in the medulla oblongata is found in the mesocephale. The fibres derived from the superficial layer of the pons pass backwards from the median groove to the posterior and superior part of the mesocephale.

Of the Cerebrum.—The constitution of each *crus cerebri* may be best understood by examining a transverse section made a little beyond its emergence from the mesocephale. Upon the surface of such a section three planes of nervous matter may be distinctly observed. The inferior one is composed of fibrous matter, continuous below with that of the mesocephale and the anterior pyramids, and which passes upwards to the corpus striatum. Immediately above it is a remarkable mass of a peculiarly dark, almost black, matter, which constitutes the well-known *locus niger* of the crus cerebri. It contains large caudate vesicles, abounding in pigment, with nerve fibres passing among them, or originating from them. This black layer does not extend beyond the crus. It forms a partition between the interior or fibrous layer, and a superior one, which composes the principal portion of the crus. This consists of a grayish matter, continuous with the central portion of the medulla oblongata, or the olivary columns, and passes into the optic thalalami.

The *optic thalamus* and *corpus striatum* are large ganglia formed upon the anterior and upper extremity of each crus, and with which the nervous matter of its upper and lower planes appears to be intimately connected. The *optic thalamus* is manifestly continuous with the superior plane, or olivary columns: its colour and texture are quite of the same nature with those of that plane; and when a longitudinal section of it is carried down through the mesocephale and medulla oblongata, no distinction is apparent between the ganglion and the olivary column, so complete is the continuity of texture. The colour of these bodies has been not inaccurately compared to that of coffee largely diluted with milk (*café au lait*). This arises from the intermixture of vesicular matter with a very close interlacement of fibres.

The *corpus striatum* has a much darker colour than the optic thalamus. When a section of it is made in an oblique direction, upwards and outwards, it exhibits the striated appearance whence its name is derived. This arises from the passage of the fibres of the inferior layer of the crus into the vesicular matter of the ganglion. The fibres do not at first blend with the vesicular matter, as in the thalamus, but are collected into bundles, which are large at their entrance from the crus, but subdivide into much smaller ones, diverging from each other, and radiating through the ganglion in various directions, upwards, forwards, outwards, and backwards.

When thin sections of the corpus striatum are examined by transmitted light, the smallest bundles of fibres observable in them appear to consist of tubules reduced to their minutest dimensions, and closely united to each other. So compactly applied are they, that very little light passes through or between them. Hence they appear to be dark masses lying in the substance of the ganglion, and, from their opacity, it is very difficult to determine their exact relation to the elements of the vesicular matter. Many of the bundles, however, appear to us to attach themselves, at different parts of the ganglion, as if around a large vesicle of which, with its nucleus, we have sometimes seen indications at one extremity of the dark mass of aggregated fibres. Other bundles of fibres appear to emerge from the corpus striatum, and to contribute to form the fibrous matter of the hemisphere.

If this view of the structure of the corpus striatum be correct, it would appear, that, while a large proportion of the fibres which constitute the inferior layer of the crus penetrate that ganglion, many of them do not pass beyond it. They may be described as terminating in it,—or, more properly, if traced from above, as taking their origin or point of departure from it. Many of the fibres which seem to pass from the corpus striatum into the white matter of the hemisphere are doubtless similarly related to the former body, *i. e.*, take their rise from the vesicular matter, or, to speak more exactly, pass between the vesicular matter of the hemisphere and that of the corpus striatum. It is also highly probable that some fibres pass completely through the corpus striatum.

Thus, three sets of fibres may be described as existing in the corpus striatum; 1st, those which below enter into the formation of the crus, and above are connected with that ganglion; 2ndly, those which are connected inferiorly with the corpus striatum, and above with the cerebral convolutions; and lastly, those which pass from the white substance of the hemispheres through the corpus striatum to the crus cerebri. And of these three sets of fibres, the first serves to connect the corpora striata with the mesocephale and medulla oblongata; the second to connect the cerebral convolutions with the corpora striata; and the third to connect the convolutions with the mesocephale and medulla oblongata. It must be confessed, however, that the evidence upon which the existence of the third class of fibres rests is less satisfactory than that for the first and second, although most of those anatomists who are contented with coarse dissection seem to recognize only the third class.

The fibres of the optic thalamus are doubtless, also, continuous with some of those which form the white matter of the hemispheres; and from the intimate manner in which this body is embraced by the corpus striatum, and the close connexion which exists between them, there can be but little doubt that fibres pass from the one to the other.

Projecting from the external and posterior part of each optic thalamus, there are two small gangliform masses, similar in colour and in structure to that body. These are the *corpora geniculata, externum* and *internum* (fig. 71, *g*). Some fibres of the optic tracts appear to form a connexion with them. By a transverse section through either geniculate body into the substance of the thalamus, the distinctness of the former may be demonstrated.

A fissure which exists between the optic thalami is called the *third ventricle.* Its roof is formed by the *velum interpositum,* one of the principal internal processes of the pia mater. It contains a bridge of soft grayish matter, extending from one optic thalamus to the other. This is called the *middle* or *soft commissure.*

The free and continuous surface of the optic thalamus and corpus striatum, which projects into the anterior and middle part of each lateral ventricle, is covered by a delicate epithelium, which is continuous with, and of the same nature as, that which lines the whole interior of the ventricles. This epithelium is, probably, ciliated. Beneath it we find a layer of nucleus-like particles, which also extend over the whole internal surface of the ventricles.

The *pineal body,* or *gland* as it has been miscalled, is placed immediately behind the posterior extremity of the third ventricle. It is a cone-shaped body, of a dark gray colour, intimately connected with the deep surface of the velum interpositum, a process of which encloses it and adheres closely to it. It rests in a groove between the nates: its base is turned forwards towards the third ventricle, and its apex is directed downwards and backwards. No part of its base is contained in the third ventricle; but it is connected to the inner surfaces of the thalami by some fibres which pass forwards from each angle of its base. These are called the *peduncles,* or *habenæ,* of the pineal gland. A cord of transverse fibres, some of which appear to be continuous with the peduncles, is situated beneath the base of the body: most of these fibres are connected with the posterior extremity of each thalamus, and constitute what is called *the posterior commissure.*

The pineal body consists principally of large nucleated vesicles, and contains some tubular fibres. In a cavity which is formed towards its base, is contained a mass of sabulous matter, which is composed of phosphate and carbonate of lime. To this Sœmmering gave the name *acervulus.* It is found only in subjects after seven years of age, and is in a great degree peculiar to the human subject.

The structure of the pineal body is very imperfectly known; and although its office has been a theme for some of the wildest speculators in physiological theories, we are still utterly in the dark respecting it.

Of the Cerebral Hemispheres.—The hemispheres of the brain are ovoid masses, which in man constitute by far the largest portion of the encephalon. All that mass of nervous matter which is external and superficial to the optic thalami and corpora striata constitutes the hemispheres properly so called. A vertical fissure separates the right and left hemispheres, which, although not perfectly symmetrical, very closely resemble each other. This fissure contains the great falciform process of the dura mater, which thus forms a septum between the cerebral hemispheres.

When a horizontal section is made through either hemisphere, an oval surface is exposed (*centrum ovale* of Vieussens), which consists of an area of white or fibrous matter, bounded by a waving margin of gray. The latter is about an eighth of an inch in thickness: it is covered on its exterior by pia mater, from which innumerable minute vessels penetrate it; and within it adheres intimately to the white matter, the fibres of which extend into it, and mingle with its elements.

In examining the surface of a hemisphere from which the pia mater has been stripped, the peculiar folded arrangement of it is manifest. These folds, commonly known as the *convolutions* of the brain, resemble the rugæ which are produced in the mucous membrane of the stomach when its muscular coat is very much contracted. They are evidently destined to pack into a small compass a large surface of vesicular matter. A sulcus separates each convolution from the neighbouring one. The gray matter is found at the bottom of the sulci, as well as upon the prominences of the folds, and its union with the fibrous matter takes place equally in the one as in the other situation. A sulcus, therefore, contains the gray (vesicular) and white (fibrous) elements as distinctly as a fold or convolution. It is evident, that if the surface of gray did not exceed that of the white matter, folds or convolutions would not be necessary, but a simple expanse of the former would suffice to cover the surface of the latter. The convoluted arrangement increases the vesicular surface to an immense extent, without occupying much additional space; and, by the prolongation of the fibres, which correspond to the concavities of the convolutions, some distance beyond those which penetrate the gray matter of the sulci, the fibrous matter is adapted to it.

The existence of convolutions on the surface of the hemispheres affords evidence of a large relative amount of the dynamic or vesicular nervous matter in those segments of the brain, and their number and complexity are a measure of the extent to which the vesicular surface is increased. Of two brains, equal as regards bulk, and occupying the same space, that which has the more numerous convolutions on its surface has the greater quantity of vesicular matter, and must be regarded as physiologically the more potential.

A remarkable gradation is observable as regards the number of the cerebral convolutions from the lowest mammalia up to man. Some of the Rodentia, Cheiroptera, and Insectivora, occupy the lowest place; and monkeys, the elephant, and the whale, rank next to Man, in whom the convolutions reach their highest point of development. In the rat, mole, &c., the surface of the brain is perfectly smooth: and the only tendency to complication which it exhibits is to be found in the convolution of the gray matter at the fissure of Sylvius. The brains of these animals resemble, in this respect, to a striking degree, those of birds, which are equally destitute of all semblance of a convolution. But in the rabbit, guinea-pig, beaver, &c., the occurrence of certain fissures on the surface of the hemispheres, and the greater depth of the fissure of Sylvius, denote the first steps in the development of convolutions.

A further stage of development is indicated by the existence of certain rounded folds which generally take a direct course parallel to the long axis of the hemispheres. These folds are but few in number, and quite simple, but may be readily distinguished from the rest of the cerebral surface, by the fissures which bound them.

However complicated and numerous the convolutions of the most highly developed brains may be, it cannot be supposed that their arrangement is accidental, or has reference merely to the space within which the brain is enclosed. On the contrary, there seems no doubt that the position, size, and connexion of certain primary folds influence mainly the number and variety of those which occupy the intervening spaces. This interesting point has been strongly insisted upon by M. Leuret, who shews, by comparison of the most completely convoluted brain with those in which the folds are few and simple, that the convolutions of the latter, which are, as it were, the original landmarks in this intricate arrangement of the cerebral surface, may be demonstrated in each successive group of brains which form a stage in the ascending series.

Taking the brain of the fox as the standard of comparison, M. Leuret* describes in it six obvious convolutions, prominently marked on the surface of its hemispheres. Four of these are *external,* the uppermost of which occupies also the principal portion of the superior surface; one is *internal*, and situate immediately above and parallel to the corpus callosum; while the sixth is on the inferior surface of the anterior lobe, and rests upon the orbit, whence it is named *supra-orbitar.* Of the four external, the inferior one bounds the fissure of Sylvius above, in front, and behind; and its relation to that fissure enables the observer to distinguish it very readily. The three remaining ones, curved similarly and parallel to the first, and to each other, occupy the remainder of the external, and, in pari, the superior surface of the hemisphere.

M. Leuret distinctly traces these convolutions in other groups of animals in which the general organization of the brain has manifestly acquired a considerable increase. Some of them, however, are fissured, or exhibit a tortuous appearance; or one or more small folds unite neighbouring convolutions at one or more points; or a fissure may be of such depth as to divide a convolution at one extremity into two, either or both of which may form a juncture with others. Thus, from a few primary or fundamental convolutions, a highly complicated surface of the brain may be formed, by their subdivision, by their tortuosity, and by their junction at various points, through the intervention of straight or tortuous secondary folds.

In some animals, however, the primary convolutions may even be less numerous than those above mentioned; and yet the surface of the brain may appear more complex, owing to the tortuosity of those which do exist, and their subdivision into, or junction with, numerous secondary folds. This is the case in that group of which the sheep forms the type. There are but two primary convolutions on the external surface, one of which corresponds to that of the fissure of Sylvius in the fox, the other to the one immediately above it; and there are the internal convolution and the supra-orbitar one, making in all only four primary convolutions. Yet the surface of the sheep's brain exhibits a much greater number of folds than that of the fox.

On the other hand, when the brain has acquired an enormous increase of size, as in the elephant and in man, new convolutions

* Professor Owen has pursued the same subject extensively, and has given his results in his lectures at the Royal College of Surgeons; but we believe these have not yet been published.

seem to be added to the primary ones met with in inferior groups, and the secondary folds are greatly increased in number. The additional convolutions are found chiefly at the superior and anterior part of the hemisphere.

In the human brain the following convolutions are constantly present, and resemble the primitive ones, which have been already referred to in the brains of the inferior animals. The *internal* one is always well marked; it lies parallel to the corpus callosum, overlapping it slightly on either side. In front it winds round the anterior margin of the corpus callosum, and is connected with the convolutions of the anterior lobe; posteriorly it divides, appears to be continuous with some posterior convolutions, and passes into the middle lobe, forming the hippocampus major. Numerous small folds pass from its upper edge to the superior convolutions. The *supra-orbitar* convolution is well developed, and bears a constant relation to the fissure for the olfactory process. The fissure of Sylvius is bounded by a tortuous *external* convolution, which forms numerous connexions with others on the external surface of the brain. In this fissure is found constantly a group of shallow convolutions, which forms what is been called by Reil, the island, *insula,* from their isolated position, having only deep-seated connexions in the vicinity of the corpus striatum. Some *longitudinal* convolutions are found on the superior and on the inner surfaces of the hemispheres, uniting with neighbouring ones by means of numerous transverse folds.

According to Leuret, that only can be properly called a convolution which is primary; and these, for the most part, take a direction in the length of the brain. Those which form angles with the primary convolutions are, in his estimation, mere folds derived from them, and connecting them to others. When the convolutions are very highly developed, as in man and the elephant, their numerous undulations obscure in a great degree their real direction. Hence many of the primary convolutions in the human brain seem to take a vertical direction.

There are, however, other differences in the convolutions, whether of the brains of the same or of different groups, besides those dependent on form and degree of undulation. These are referrible to their depth and their thickness. Animals, even of the same group, or of the same species, exhibit much variety with respect to these points. The wolf has precisely the same convolutions as the fox; but those of the former are deeper, and thicker, as well as more undulating than those of the latter. Much difference is also observable in these respects in the human brain. The convolutions of the female brain are not so deep nor so thick as those of the male. Age, too, causes a marked difference. The convolutions of the child just born, besides being much more simple, and having fewer undulations, are less deep and less thick than those of the adult; and in old age, when the brain has shrunk, the mental faculties being less vigorous and active, the convolutions have become much smaller in every dimension, and water is apt to accumulate in the intergyral spaces.

In man, the convolutions of the right and left hemispheres do not present a perfect symmetry. It is important, however, to notice, that careful examination will invariably display the same essential convolutions on each side, although they present such striking differences in detail that it is at times difficult to recognize the likeness; and it is not a little remarkable, that, in general, the lower the development of a brain, the more exact will be the symmetry of its convolutions. Thus the brains of all the inferior mammalia, even of those which make the nearest approach to man, are exactly symmetrical. The imperfectly developed brain of the child exhibits a similar symmetry; and that of the inferior races of mankind, in whom the neglect of mental culture, and habits approaching those of the brute, are opposed to the growth of the brain, also presents a symmetrical disposition of the convolutions.

A convolution consists of a fold of the gray, or vesicular matter, enclosing a process of the fibrous. The gray matter of neighbouring convolutions is obviously continuous throughout at the bottoms of the sulci, so that it forms one unbroken although undulating sheet over the whole convoluted surface of the brain. That portion of the gray layer which is in contact with the pia mater is purely vesicular, *i. e.* unmixed with nerve-tubes, with the exception of a few stray ones on the surface; but blood-vessels penetrate it in very great numbers. The more deeply seated portion, however, contains very numerous tubular fibres, which become larger as they approach the white matter. It is very plain, that a large proportion of the constituent fibres of the white matter of the convolutions penetrate the gray matter: these appear to enter it more or less at right angles to that portion of the gray surface with which they are more immediately in relation; and, on the other hand, they converge inwards towards the central parts of the brain, the corpora striata and optic thalami. A large proportion, therefore, of the white substance of the hemispheres, the *centrum ovale*, consists of fibres which establish a communication between the gray undulating surface and these central gangliform bodies.

We are unable, however, to state that all the fibres of the convolutions take this inward direction. Some of them, it has been asserted, pass from convolution to convolution, uniting those immediately adjacent, as well as the more remote. Such fibres, did they exist, would pass at right angles to those above described, and parallel to the gray surface. They would constitute *intergyral commissures*. But the existence of such a series of fibres rests on a foundation too uncertain to warrant us in speaking confidently respecting it. When a brain which has been hardened by long immersion in alcohol is torn along the surface of the convolutions, the torn surfaces take on a fibrous appearance. But nothing of the kind can be shewn in the fresh brain, in which the direction of the fibres which converge to the corpora striata may be as easily demonstrated as upon the hardened one.

The gray matter of the convolutions does not exhibit an uniform colour throughout its entire thickness. Much depends, as regards the depth of colour of the whole layer, upon the quantity of blood in its vessels. Compare the gray matter of an anæmic brain with that of a healthy one, or, still more, of a congested one, and the difference cannot fail to strike the most superficial observer. The external portion has the darkest colour, and the internal in general the lightest. In some convolutions, however, the intermediate layer is white, and appears on the section like a white line separating the inner from the outer layers. This is very obvious in the convolutions forming the exterior of the descending horn of the lateral ventricles. This white layer contains fine nucleus-like particles, similar to those which form the intermediate layer of the gray matter of the cerebellum; a coincidence of structure between certain convolutions of the brain, and the gray matter of the cerebellum, which, doubtless, is not without some physiological significance.

Certain systems of fibres exist in the cerebrum, which seem very evidently to unite portions of the same, or of opposite hemispheres. The most obvious of these commissures are, the *corpus callosum*, the *anterior commissure*, the *posterior commissure*, the *soft commissure*, the *superior longitudinal commissure*, and the *fornix*. All, except the two last, are transverse, and unite parts of the hemispheres of opposite sides.

The *corpus callosum* is a thick stratum of transverse fibres, bent at its anterior and posterior extremities, situate between the hemispheres, and forming a floor to a portion of the great median fissure which separates them. Its fibrous structure is very apparent to the naked eye, the fibres being collected in coarse bundles. On each side it penetrates into the hemisphere, under cover of the internal convolution already mentioned, which overhangs it in its entire length. It thus connects the anterior, middle, and part of the posterior lobes of each hemisphere; at least, its fibres penetrate the hemisphere at these parts. Foville describes the fibres of this commissure as being derived partly from the posterior columns of the medulla oblongata, from the optic thalami, from the corpora striata, and, lastly, from the fibrous matter of the hemispheres; and although the demonstration of these numerous sources of origin of these fibres is attended with much difficulty, it nevertheless seems highly probable that the numerous fibres, of which so extensive a stratum is formed, would derive their orgin from several sources.

The corpus callosum is crossed from before backwards along the median line by two stripes of longitudinal fibres, which, although easily separable, generally lie in close apposition with each other, and form a kind of raphé, dividing the upper surface of the corpus callosum into two equal and symmetrical portions. These fibres seem to be commissural in their office.

The *anterior commissure* is a remarkable bundle of transverse fibres, which passes from one hemisphere to the other. It is in its centre a cylinder of fibrous matter, a little thicker than a crów-quill, but becoming very much flattened and expanded at its extremities. Its central part is seen at the anterior extremity of the third ventricle, in front of the anterior pillars of the fornix, crossing from side to side, quite free, and unconnected with nervous matter. It plunges on either side into the anterior extremity of the corpus striatum, and, passing through it, its fibres diverge and spread out into the white matter at the floor of the Sylvian fissure, and near the anterior perforated space.

The *posterior commissure* crosses the posterior extremity of the third ventricle, and passes transversely between the optic thalami. It is a slender cylinder of fibrous matter, which lies immediately above the anterior orifice of the aqueduct of Sylvius. On each side it seems to sink into the posterior part of the optic thalamus. The base of the pineal body rests upon it, and is connected with it by fibrous matter, which is continuous with the peduncles.

The *soft commissure* is a soft pale-gray layer consisting of vesicular matter with nerve-tubes, which stretches from one optic thalamus to the other, having no other connexion, and being free on its upper as well as its under surface. This layer, thus extended horizontally between the thalami, divides the third ventricle into a superior and an inferior portion. As it comprises vesicular matter, it is not a commissure in the same sense as the others, which contain none.

The *superior longitudinal commissure* is enclosed in the internal convolution overhanging the corpus callosum. Posteriorly it passes over the posterior border of the corpus callosum, to the under part of the middle lobe, where it is chiefly connected with the hippocampus major. Anteriorly it winds over the front border of the corpus callosum to join the lower convolutions of the anterior lobe in front of the fissure of Sylvius. Thus it takes a course similar to that of the fornix, though more extensive and superficial.

The *fornix* or *vault* is the most extensive, and in every way the most remarkable of the cerebral commissures. It is placed immediately beneath the corpus callosum, with the posterior half of which it is intimately connected, and from which it is with difficulty separated. A principal portion of the fornix consists of a horizontal lamella of fibrous matter, parallel to the corpus callosum, of a triangular shape, with the apex forwards (*corpus fornicis*). The base is enclosed by the posterior reflection of the corpus callosum, the terminal transverse fibres of which are seen on its interior surface, forming the appearance which has been designated *lyra*.

The fornix may be divided along the middle line into two equal and symmetrical portions, one belonging to each hemisphere. Sufficient indication of its double form is evinced by the prolongation from its apex of two cylindrical cords, which curve forwards and downwards, then backwards, with their convexities touching the posterior border of the anterior commissure. These are the *anterior pillars* of the fornix. In their descent they diverge slightly from each other, leaving an interval between them, through which the anterior commissure appears. These pillars form the anterior boundary of the *foramen commune anterius*, through which the lateral ventricles communicate with the third, and with each other.

Each anterior pillar of the fornix in its descent penetrates the anterior and inner part of the optic thalamus. Here it is surrounded by vesicular matter, which may be readily scraped away from it. Numerous striæ of fibrous matter join the pillar as it passes through the vesicular matter; their constituent fibres, doubtless, being derived from the thalamus. Finally, each pillar terminates in a small spherical body at the base of the brain. These bodies, called *corpora mamillaria*, are white outside, but, when cut into, exhibit a reddish-gray colour, like that of the optic thalami. They contain nerve-tubes and vesicular matter in considerable quantity, and therefore resemble ganglia in structure. A considerable fasciculus of fibres connects each mamillary body with the optic thalamus.

From each angle of the base of the fornix a broad band of fibrous matter passes outwards, and spreads partly into the posterior horn of the lateral ventricle, and partly into its descending horn. These bands constitute the *posterior pillars* of the fornix. They connect themselves with certain convolutions which project into the posterior and inferior cornua of the lateral ventricles; in the latter with the hippocampus minor, and in the former with the hippocampus major.

The fornix consists of longitudinal fibres, unmixed with vesicular matter, save in the optic thalami and corpora mamillaria. The superior surface of the body of the fornix is connected to the inferior surface of the corpus callosum, at its base apparently by the direct adhesion of the fibres of the two planes; but towards its apex by the *septum lucidum*, which extends vertically from the middle line of the inferior surface of the corpus callosum to that of the superior surface of the fornix.

From the great extent of the fornix, and the numerous connexions which its pillars form, it is plain that it must serve as a commissure to many and distant parts. Each half of it is a longitudinal or antero-posterior commissure for the hemisphere of its own side. It is not improbable that some of the convolutions contain antero-posterior commissures for the superficial part of the hemisphere; such is certainly the case with the longitudinal convolution above the corpus callosum. The fornix, however, connects deep-seated parts, for it passes between the optic thalamus and the deep convolutions of the posterior and middle lobes.

The *septum lucidum* consists of two layers of fibrous matter, which enclose a space or cavity called the *fifth ventricle*. The fibres of this layer radiate upwards and forwards, and connect the anterior pillars of the fornix with the corpus callosum. Each fibrous layer is covered on its outside by a layer of nuclear particles, which again is covered by the membrane of the lateral ventricle.

A band of fibrous matter, which belongs to the same system of commissural fibres as the fornix, is found, on each side, in the groove between the corpus striatum and optic thalamus. This is called *tænia semicircularis*. It may be described as connected with the corpus mamillare, in much the same way as the anterior pillar of the fornix. Traced from this point, it is found to penetrate the optic thalamus, following the general course of the anterior pillar of the fornix, but slightly diverging from it, and to emerge from the thalamus in the anterior part of the groove between it and the corpus striatum, whence it passes backwards, outwards, and downwards into the inferior cornu of the lateral ventricle.

Other structures exist in the brain, which seem likewise to act as commissures to the parts between which they are placed. Thus, between the crura cerebri a layer of fibrous matter, mingled with a few vesicles, is placed, which fills up the angle formed at their divergence; this layer is remarkable for being perforated by numerous foramina, which give passage to the blood-vessels of the locus niger. It is called the *pons Tarini;* it probably connects the gray matter of the crura.

The *innermost fibres of the optic tracts* are evidently commissural. These fibres form an arch, which crosses the tuber cinereum. In the mole, they are the only fibres of the optic tracts existing: those which form the optic nerves are not present. These fibres connect the quadrigeminal tubercles and the geniculate bodies of opposite sides.

The *tuber cinereum* is a remarkable layer of vesicular matter, with which nerve-tubes freely intermingle, which extends from the mamillary bodies forwards to the posterior reflection of the corpus callosum, and has intimate connexions with the anterior pillars of the fornix, the optic tracts, the septum lucidum, and, at the floor of the third ventricle, with the optic thalami. An infundibuliform tube passes from it down towards the pituitary gland, which is situate in the sella Turcica.

It is curious how few are the fibres which seem to connect the cerebrum and cerebellum. The only ones to which this office can be assigned are those which form the processus cerebelli ad testes. Hence these structures may more fitly be denominated *cerebro-cerebellar commissures.* They extend between the cerebellum on the one hand, and the optic tubercles and thalami on the other.

Of the manner in which the commissures connect the various parts between which they are placed, it is difficult to form an exact opinion. Are the commissural fibres directly continuous with those of the segments which they unite? or do they intermingle or interlace with them in some intricate way, so that they may come into intimate or frequent contact? Or, do they, like other fibres, blend with the gray matter, and thus connect the really dynamic portion of the segments? This latter view seems to be the most probable.

The *pituitary body* or *hypophysis* is a glandiform mass lodged in the sella Turcica, and surrounded by the coronary sinus. It is connected with the brain by the infundibular process, the small extremity of which is attached to its superior concave surface.

This body consists of two lobes, of which the anterior is much the larger; and which also differ in point of colour, the anterior being of a yellowish gray, the posterior more similar to the gray matter of the brain. The former is considerably denser and firmer than the latter, which does not differ in consistence from the cerebral gray matter. The infundibulum is chiefly connected with the posterior lobe.

In point of structure, this body resembles somewhat the vesicular matter of the brain. We find in it large vesicles with distinct nuclei and nucleoli lodged in a granular matrix, and between them numerous bundles of white fibrous tissue. These are most numerous in the anterior lobe. Its use is quite unknown.

Of the Ventricles of the Brain.—By the apposition of the two hemispheres of the brain along the median plane, a fissure-like space is enclosed beneath the corpus callosum and fornix, limited in front by the anterior pillars of the latter, and behind by the posterior commissure; this is the *middle* or *third* ventricle. This fissure is closed inferiorly by the pons Tarini, mamillary tubercles, and tuber cinereum; its roof is formed by the *velum interpositum,* a process of pia mater, which separates it from the body of the fornix. It communicates posteriorly with the fourth ventricle through the aqueduct of Sylvius (*iter a tertio ad quartum ventriculum*), and immediately behind the anterior pillars of the fornix it freely opens into each lateral ventricle. At the same situation, the velum interpositum and the choroid plexuses communicate with each other. The optic thalami form the lateral boundaries of the third ventricle, and its cavity is crossed by the soft commissure.

The *lateral* ventricles result from the folding of the convoluted surface inwards and downwards. By their extension inwards, and their junction along the median line by the corpus callosum, the horizontal portion of each ventricle is enclosed; and by the folding inwards of the inferior convolutions, posterior to the fissure of Sylvius, the inferior horn is formed. The horizontal portion extends into the anterior lobe (*anterior* or *frontal horn*), and into the posterior lobe (*posterior* or *occipital horn*). The central part of the horizontal portion is separated from the third ventricle by the body of the fornix. In this portion of the ventricle are seen the upper surfaces of the corpus striatum and optic thalamus, with the tænia semicircularis between them, covered by the lamina cornea. The thalamus is partly concealed by the choroid plexus. The descending or inferior horn (*sphenoidal horn*) communicates with the body of the ventricle just behind the corpus striatum, and from that point passes downwards and outwards, and then forwards and inwards. It contains a remarkable convolution, the *hippocampus major,* which projects into it, and is a continuation of that enclosing the superior longitudinal commissure; this is covered by an expansion of fibrous matter continuous with the posterior pillars of the fornix. The posterior horn contains a similar but smaller convolution, called *hippocampus minor.*

The inferior horn of the lateral ventricle contains a considerable portion of the choroid plexus. This enters at its inferior extremity between the hippocampus major and the crus cerebri, and passes upwards into the horizontal portion of the ventricle.

The *fourth* and the *fifth* ventricles have been already described.

All the ventricles are lined by a very delicate membrane, similar in structure to serous membrane. It is covered by a fine epithelium consisting of polygonal scales, and provided with cilia, which were first observed by Purkinje and Valentin. This epithelium is found covering the surface not only of the wall of the ventricle, but also of the pia mater within it, the choroid plexuses, and the deep surface of the velum interpositum. It is by means of the reflection of this membrane upon the intraventricular processes of pia mater, that the ventricles are closed at those points where nervous matter does not exist, such as the inferior cornua of the lateral ventricles, and the inferior extremity of the fourth ventricle. There is, therefore, no direct communication of these cavities at these points with the subarachnoid space; and, if fluid pass from one to the other, it must be by filtration through the delicate ventricular membrane.

In a state of health, there is little or no fluid in the lateral or other ventricles of the brain. Their inner surfaces are doubtless in contact, but lubricated with a moisture, as all serous surfaces are. When fluid is found in them, it results either from changes which take place after death, or from some morbid process during life. A state of anæmia, or an impoverished condition of the blood, in which its colouring matter and its fibrine are found in small quantity, is very favourable to the effusion of fluid into the ventricles.

It may serve, in some degree, to convey a clearer general idea of the anatomy of the brain, if, in conclusion, we explain the course which the nervous force might, and probably does follow, when developed in any particular segment of this complex organ.

If we suppose the source of power to be the convolutions on either side, the nervous force would be propagated by the fibres of the hemisphere to the vesicular matter of the corpus striatum; from which it would pass along the fibres of the inferior layer of the crus cerebri, through the mesocephale, to the anterior pyramids of the medulla oblongata; along which it would be conveyed to the opposite half of the spinal cord, exciting the nerves which spring from that segment. Supposing this to be the route in which the impulse of volition is propagated to the muscles, it becomes very easy to understand why a state of paralysis must ensue, when an apoplectic clot, or other morbid deposit in any part of the course above described, compresses or ruptures the fibres, or when a state of softening destroys their vital powers, or causes a solution of their continuity. If the seat of disease be in the white matter, the channels along which the nervous power travels will be interrupted; if it be in the gray matter, the sources of nervous power are impaired. In all cases the extent of the paralysis will be proportioned to that of the lesion, and for the most obvious reasons.

If the cerebellum be the source of power, the nervous force will travel from either hemisphere along the fibres of the crus, and by those of the restiform body to the spinal cord, and from the continuity of the former with the posterior column of the latter it is probable that this column would be more immediately excited.

So little is known of the precise channels through which impressions created at the periphery are propagated in the central organ, that we can hardly do more than speculate on the subject. We may, however, fairly conclude, that those segments with which nerves admitted to be sensitive are in close connexion, must be instrumental in the propagation of the nervous power, when excited by sensitive impressions; and hence we are led to assign to the olivary columns of the medulla oblongata, and their continuations in the mesocephale, with the optic tubercles and the thalami, a considerable share in this office, inasmuch as the auditory, the fifth, and the optic nerves, are intimately connected with them.

And admitting, for the present, that the hemispheres are the common centre of sensitive impressions, it is easy to understand how nervous power, excited by the impulse of sound upon the ear, for example, may be propagated along the auditory nerves to the olivary columns in the fourth ventricle, and thence to the optic thalami, in which are found many fibres which are continuous with those of the hemispheres, and capable of propagating the nervous force to the convolutions.

To this it may, however, be objected, that perfect sensation is frequently coexistent with a cerebral lesion, sufficient to produce very complete paralysis of motion, and that an enduring paralysis of sensation is a rare accompaniment of cerebral disease. But such facts do not so much militate against these views, as they serve to denote that the channels of sensation are more numerous than those of motion; and that, if one route be interrupted, another is easily opened. It may be, that the commissures are valuable instruments for this purpose; and it is highly worthy of notice, that no segment of the cerebrum has so many commissures, either with the opposite or its own side, as the optic thalamus.

It should be borne in mind that the foregoing remarks are partly conjectural, and that they are introduced rather as a convenient form of illustration, than as implying more than a probability of their general correctness and accordance with the best established views.

Of the Circulation in the Brain.—An organ of such great size, of such high vital endowments, so active, and which exerts so considerable an influence upon all other parts of the body, must necessarily require a large supply of the vital fluid. Hence we find that the blood-vessels of the brain are numerous and capacious. Four large arteries carry blood to it; namely, the two *internal carotids*, and the two *vertebrals*. Each *carotid* penetrates the cranium at the foramen on the side of the sella Turcica, and almost immediately divides into three branches, the *anterior* and the *middle cerebral* arteries, and the *posterior communicating* artery.

The anterior cerebral arteries supply the inner sides of the anterior lobes of the brain: they ascend through the great longitudinal fissure, and pass along the upper surface of the corpus callosum, giving off branches to the inner convolutions of both hemispheres of the brain. These arteries anastomose with each other just beneath the anterior margin of the corpus callosum by a transverse branch, called the *anterior communicating* artery. The middle cerebral arteries, the largest branches of the carotids, pass outwards in the fissures of Sylvius, and supply the outer convolutions of the anterior lobes, and the principal portion of the middle lobes. At the inner extremity of each fissure of Sylvius numerous small branches of these arteries penetrate, to be distributed to the corpus striatum. The choroid arteries which supply the choroid plexus sometimes arise from these arteries, but also occasionally come from the carotid itself. The posterior communicating artery is an anastomotic vessel, which passes backward along the inner margin of the middle lobe on the base of the brain, and communicates with the posterior cerebral artery, a branch of the basilar.

The *vertebral* arteries having passed through the canals in the transverse processes of the cervical vertebræ, enter the cranium through the occipital foramen towards its anterior part. In their ascent they incline towards each other in front of the medulla oblongata, and at the posterior margin of the pons they coalesce to form a single vessel, the *basilar*, which extends the whole length of the pons.

The *vertebral* arteries furnish the *anterior* and *posterior spinal* arteries, and the *inferior cerebellar* arteries. These last vessels arise from the vertebrals very near their coalescence, and pass round the medulla oblongata to reach the inferior surface of the cerebellum, to which they are principally distributed.

The basilar artery sends numerous small vessels to penetrate the pons, and at its anterior extremity divides into four arteries, two on each side: these are, the two *superior cerebellar*, and the two *posterior cerebral* arteries.

The superior cerebellar arteries pass backwards round the crus cerebri, parallel to the fourth nerve, and divide into numerous branches on the upper surface of the cerebellum, some of which anastomose with branches of the inferior cerebellar artery over the posterior margin of the cerebellum. Some branches of these arteries are distributed to the velum interpositum.

The posterior cerebral arteries are the largest branches of the basilar. They diverge and pass upwards and backwards round the crus cerebri, and reach the inferior surface of the posterior lobe, anastomosing in the median fissure with ramifications of the anterior cerebral, and on the outside with branches of the middle cerebral arteries. Numerous small vessels pass from this artery at its origin, and penetrate the interpeduncular space, and one or two are distributed to the velum. Shortly after its origin, the artery receives the posterior communicating branch from the carotid.

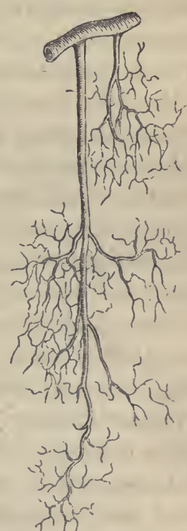
A remarkable freedom of anastomosis exists between the arteries of the brain. This takes place not only between the smaller ramifications, but likewise between the primary trunks. The former is evident all over the surface of the cerebrum and cerebellum. The latter constitutes the well-known *circle of Willis.* This anastomosis encloses a space, somewhat of an oval figure, within which are found the optic nerves, the tuber cinerum, the infundibulum, the corpora mamillaria, and the interpeduncular space. The anterior communicating artery, between the anterior cerebral arteries, completes the circle in front. The lateral portion of the circle is formed by the posterior communicating artery, and it is completed behind by the bifurcation of the basilar into the two posterior cerebral arteries. Thus, a stoppage in either carotid, or in either vertebral, would speedily be remedied. The coalescence of the vertebrals to form the basilar, affords considerable security to the brain against an impediment in one vertebral; and, should the basilar be the seat of obstacle, the anastomoses of the inferior cerebellar arteries with the superior ones would ensure a sufficient supply of blood to that organ. If either or both carotids be stopped up, the posterior communicating arteries will supply a considerable quantity of blood to the intracranial portions of them; or, if one carotid be interrupted, the anterior communicating branch will be called into requisition to supply blood from the opposite side.

Obstruction to the circulation in both carotids and both vertebrals is productive of a complete cessation of cerebral action, and death immediately ensues, unless the circulation can be quickly restored. This was proved clearly by Sir A. Cooper's experiments on rabbits. The circulation may, however, be interrupted in both carotids, or in both vertebrals, without permanent bad effect; or in one carotid or in one vertebral, provided the condition of the remaining vessels be such as not to impede the circulation in them. In cases where the neighbouring anastomotic branches are not sufficient to restore the circulation to a part from which it has been cut off by the obliteration of its proper vessel, the cerebral substance of that region is apt to experience a peculiar form of softening or wasting, which is distinguished by the absence of any discoloration by the effusion of blood, and of any new matter.

The four great channels of sanguineous supply to the brain are continued up straight from the aorta itself, or from an early stage of the subclavian. The contained columns are propelled very directly towards the base of the brain, through wide canals. Were such columns to strike directly upon the base of the brain, there can be no doubt it would suffer materially. Considerable protection, however, is afforded to the brain; first, by the blood ascending against gravity, during at least a great portion of life; secondly, by a tortuous arrangement of both carotids and vertebrals before they enter the cranial cavity, the carotid being curved like the letter S in and above the carotid canal, and the vertebral being slightly bent between the atlas and axis, then taking a horizontal sweep above the atlas, and after it has pierced the occipito-atlantal ligament, inclining obliquely upwards and inwards; thirdly, by the breaking up of the carotids into three branches, by the inclined position of the vertebrals, and by their junction into a single vessel, which takes a course obliquely upwards, and afterwards subdivides into smaller branches. Such arrangements most effectually break the force of the two columns, and, as it were, scatter it in different directions.

A further conservative provision is found in the manner in which the blood-vessels penetrate the brain. The larger arterial branches run in sulci between convolutions, or at the base of the organ; smaller branches come off from them, and ramify on the pia mater, breaking up into extremely fine terminal arteries, which penetrate the brain; or these lattter vessels spring directly from the larger branches, and enter the cerebral substance. As a general rule, no vessel penetrates the cortical layer of the brain, which, in point of size, is more than two removes from the capillaries; and, whenever any vessel of greater size does pierce the cerebral substance, it is at a situation where the fibrous matter is external, and the part perforated by foramina for the transmission of the vessels. Such places are the locus perforatus, the interpeduncular space, &c. The accompanying figure shews the manner in which the terminal arterial twigs dip vertically into the cerebral substance, and break up into a solid plexus of capillaries in the stratum of vesicular matter. The capillary plexus of the fibrous or white matter has similar characters, only its meshes are much wider (fig. 72). The capillaries of the cerebral substance are easily seen to possess an independent diaphanous wall, with cell-nuclei disposed at intervals. The smaller

Fig. 72.



Two terminal arteries leaving a branch on the surface of a convolution of the cerebrum, dipping vertically inwards, and exhibiting the mode of origin and distribution of the capillaries in the gray cortical layer. From an injected specimen. Mag. 30 diameters.

arteries and veins can also be admirably studied in the pia mater of the brain.

The venous blood is collected into small veins, which are formed in the pia mater at various parts of the surface, and in the interior of the brain. The superficial veins open by short trunks into veins of the dura mater, or into the neighbouring sinuses; the superior longitudinal, the lateral, and the strait sinuses receiving the greatest number. Those from the interior form two trunks, *venæ magnæ Galeni*, which pass out from the ventricles between the layers of the velum interpositum. The cerebral veins are devoid of valves.

We remark here, that the venous blood of the brain is returned to the centre of the circulation through the same channels as that of the dura mater, of the cranial bones, and of the eyeball: the deep jugular veins are the outlets by which the venous blood of the cranium is discharged. An obstacle, therefore, in both or either of these trunks must affect the entire venous system of the brain, or at least that of the corresponding hemisphere. A ligature tied tightly round the neck impedes the circulation, and may cause congestion of the brain. The bodies of criminals who have died by hanging exhibit great venous congestion, both of the walls and the contents of the cranium, in consequence of the strong compression to which the veins have been submitted.

We have seen, that, when the blood of one carotid artery is cut off, the parts usually supplied by it are apt to become exsangueous and softened; and this is more especially the case if the vertebral be also impacted, or the circulation in it impeded. And it has been remarked, that these effects will follow the application of a ligature to either common carotid artery.

Notwithstanding these facts, a doctrine has received very general assent, and the support of men of high reputation, which affirms that the absolute quantity of blood in the brain cannot vary, because that organ is incompressible, and is enclosed in a spheroidal case of bone, by which it is completely exempted from the pressure of the atmosphere.

The cranium, however, although spheroidal, is not a perfectly solid case, but is perforated by very numerous foramina, both external and internal, by which large venous canals in the diploë of the bones communicate with the circulation of the integuments of the head as well as with that of the brain; so that the one cannot be materially affected without the other suffering likewise. And as the circulation in the integuments is not removed from atmospheric pressure, neither can that which is so closely connected and continuous with it, be said to be free from the same influence. Still it must be admitted, that the deep position of the central vessels, and the complicated series of channels through which they communicate with the superficial ones, protect them in some degree from the pressure of the air, and render them less amenable to its influence than the vascular system of the surface.

If it were essential to the integrity of the brain that the fluid in its blood-vessels should be protected from atmospheric pressure (as the advocates of this doctrine would have us to believe), a breach in the cranial wall would necessarily lead to the most injurious consequences; yet, how frequently has the surgeon removed a large piece of the cranium by the trephine without any untoward result! We have watched for several weeks a case in which nearly the whole of the upper part of the cranium had been removed by a process of necrosis, exposing a very large surface to the immediate pressure of the atmosphere; yet in this case no disturbance of the cerebral circulation existed. In the large and open fontanelles of infants we have a state analogous to that which art or disease produces in the adult: yet the vast majority of infants are free from cerebral disease for the whole period during which their crania remain incomplete; and in infinitely the greatest number of cases in which children suffer under cerebral disease, the primary source of irritation is in some distant organ, and not in the brain itself.

Neither can it be said that the brain is incompressible. That only is incompressible, the particles of which will not admit of being more closely packed together under the influence of pressure. That the brain is not a substance of this kind, is proved by the fact that, while it is always undergoing a certain degree of pressure, as essential to the integrity of its functions, a slight increase of pressure is sufficient to produce such an amount of physical change in it as at once to interfere with its healthy action. Too much blood distributed among its elements, and too much serum effused upon its surface, are equally capable of producing such an effect.

Majendie's experiments, alluded to at p. 253, shew that the brain and spinal cord are surrounded by fluid, the pressure of which, probably, antagonises that which must be exerted through the blood-vessels. The removal of this fluid disturbs the functions of these centres apparently by allowing the vessels to become too full. The pressure exerted by the former we shall call the fluid-pressure from without the brain; that by the blood, the pressure from within. As long as these two are balanced, the brain enjoys a healthy state of function, supposing its texture to be normal. If either prevail, more or less of disturbance will ensue. Their relative quantities, if not in just proportion, will bear an inverse ratio to each other. If there be much blood, the surrounding fluid will be totally, or in a great measure, deficient; if the brain be anæmic, the quantity of surrounding fluid will be large.

The existence of these two antagonising forces may be taken as a proof that either of them may prevail; and therefore, from the existence of the cerebro-spinal fluid we may infer that the actual quantity of blood circulating in the brain is liable to variation.

This fluid is a valuable regulator of vascular fulness within the cranium, and a protector of the brain against too much pressure from within. So long as it exists in normal quantity, it resists the entrance of more than a certain proportion of blood into the vessels. Under the influence of an unusual force of the heart, an undue quantity of blood may be forced into the brain; the effects of which will be, first, the displacement of a part, or of the whole surrounding fluid, and, secondly, the compression of the brain.

On the other hand, the brain may receive two little blood. In such a case, if the surrounding fluid do not increase too rapidly, the requisite degree of pressure will be maintained, and the healthy action of the brain preserved. But, if the brain be deprived of its due proportion of blood by some sudden depression of the heart's power, there is no time nor source for the pouring out of new fluid, and a state of syncope, or of delirium, will ensue. Such seems to be the explanation of those cases of delirium which ensue upon hæmorrhages, large bleedings, or the sudden supervention of inflammation of the pericardium or endocardium. In many of these cases, however, it is important to notice, that the blood is more or less damaged in quality, deficient in some of its staminal principles, or charged with some morbid matter; and this vitiated state of the vital fluid has, no doubt, a considerable share in the production of the morbid phenomena.

The following inferences, which are of practical application, will form a suitable conclusion to these remarks on the circulation within the cranium.

1. That the brain, although not so amenable to the influence of atmospheric pressure as more superficial parts, is sufficiently so to admit of variations in the quantity of its circulating fluid.

2. That, consequently, general or local bleeding will exert the same kind of influence upon the circulation in the brain, as in other organs, so far as relates to diminishing the quantity of blood in it.

3. But that the brain is liable to suffer from the loss of blood in a different way from other viscera, inasmuch as copious bleeding may occasion serious disturbance in the functions of the brain by lessening the force of the heart's action, and thereby depriving the brain of that amount of pressure on its vascular surface which seems essential to its healthy action.

4. That the depression of the heart's force, from any other cause, is capable of producing similar cerebral disturbance for the same reasons.

The following works may be consulted upon the subjects treated of in this chapter.

Cruveilhier's Anat. Descr. t. iv.—Meckel, Anat. Gén. Descr. et Pathol. t. ii. —Reil's Essays, translated in Mayo's Anat. and Phys. Commentaries.—The article Nervous Centres in the Cyclopædia of Anatomy.—Mayo's Plates of the Brain.—Stilling und Wallach, Untersuchungen über die Textur des Rückenmarks. Leipz. 1842.—Stilling, über die Textur und Function der Medulla oblongata. Erlang. 1843.—Foville, Anat. du Syst. Nerveux. Par. 1844.—Leuret, Anat. comparée du Syst. Nerveux. Par. 1839.

The subject of the circulation in the brain has been treated with great acuteness and learning by Dr. George Burrows, in the Lumleian Lectures for 1843, Lond. Med. Gazette, vol. xxxii.

CHAPTER XI.

OF THE SPINAL NERVES.—OF THE ENCEPHALIC NERVES.—METHOD OF DETERMINING THE FUNCTIONS OF NERVES.—OF THE FUNCTIONS OF THE SPINAL CORD AND ENCEPHALON.

Before we can satisfactorily investigate the functions of the cerebro-spinal centre, or of its various segments, it will be necessary to give some account of the nerves which are connected with them.

These nerves are described in two classes, the *spinal* and the *encephalic.* The former class consists of all those which arise from the spinal cord, and emerge from the spinal canal through orifices in its wall. The latter consists of those which are connected with the encephalon.

Of the Spinal Nerves.—There is a pair of spinal nerves for each pair of intervertebral foramina on the same level, and for those between the atlas and occiput. We can thus enumerate in all thirty-one pair of nerves having their origin from the spinal cord, exclusive of the spinal accessory nerve, which is connected with the upper part of the cervical region.

The spinal nerves have the following very constant characters. Each has its origin by *two roots,* of which the anterior is distinctly inferior in size to the posterior (fig. 61, *p, a,* p. 222). The ligamentum denticulatum is placed between these roots. Each root passes out by a distinct opening in the dura mater. Immediately after its emergence a ganglion is formed on the posterior root, and the anterior root lies imbedded in the anterior surface of the ganglion, and inclosed in the same sheath, but without mingling its fibres with those of the ganglion. Beyond it, the nervous fibres of both roots intermingle, and a compound spinal nerve results. The trunk thus formed passes immediately through the intervertebral canal, and divides into an anterior and posterior branch (fig. 61, *a′, p′*). The former is in general considerably the larger. The latter passes backwards, and sinks in among the muscles of the posterior regions of the trunk. The anterior branches in the cervical, lumbar, and sacral regions form large and intricate plexuses, (cervical, axillary, lumbar, and sacral), from which nerves are furnished to the extremities and the anterior part of the trunk.

The first spinal nerve, called by Winslow the *suboccipital*, offers an exception to this arrangement. Generally it arises by two roots, of which, however, the anterior is the larger. Sometimes it has only one root, corresponding to the anterior.

The spinal nerves are arranged naturally in classes, according to the regions of the spine in which they take their rise. We number eight in the cervical region, the suboccipital included; twelve in the dorsal region; five in the lumbar, and six in the sacral regions. All the nerves after the second pass obliquely outwards and downwards, from their emergence from the spinal cord to their exit from the vertebral canal; and this obliquity gradually increases from the higher to the lower nerves, so that the inferior ones are nearly perpendicular; and, as their intra-spinal course is of some length, they are collected into a leash, which constitutes the *cauda equina*.

All the spinal nerves arise from the cord by separate fasciculi of filaments, which, as they approach the dura mater, converge to each other, and are united together to constitute the anterior or the posterior roots. The posterior roots arise at a pretty uniform distance from the posterior median fissure in all regions of the cord, indicating but a very trifling change in the thickness of the posterior columns throughout their entire course. Not so the anterior ones: they are farthest from the anterior median fissure in the neck, but very near it in the dorsal region; this difference being due to the variation in the thickness of the antero-lateral columns in the different regions. The ganglia on the posterior roots are always proportionate in size to the roots themselves.

In tracing the mode of connexion of the roots of the spinal nerves with the cord, great care is required, from the sudden change of consistence which their fascicles experience on penetrating the substance of the cord. They lose the sheath of pia mater which gave firmness to that part which is external to the cord, and soon break up into their component fibrillæ. For this reason, the specimen employed for the dissection should be quite recent, and slightly hardened by previous immersion in spirit.

The anterior roots penetrate the lateral part of the antero-lateral columns. Their fibres soon radiate, some passing upwards and inwards, others horizontally inwards towards the centre of the cord, mingling, no doubt, with the elements of the vesicular matter composing the anterior horn. It is a matter of uncertainty, whether the fibres which take an upward course pass into the gray matter, or simply merge into the longitudinal fibres of the cord and pass upwards to the brain. Mr. Grainger's researches lead him to suppose that each root consists of a double set of fibres—one which penetrates, and has its origin from, the gray matter, and the other which is continuous with the longitudinal fibres. This view is considered to derive probability from the hypothesis which ascribes the voluntary and involuntary actions of the cord to two distinct series of fibres, of which one is under cerebral influence, and the other merely excito-motory; and it might be acknowledged to do so, if the necessity of distinct fibres for the two kinds of action were first proved. It is possible, however, that *all* the fibres penetrate and arise from the gray matter. But we have seen nothing to justify Stilling and Wallach's assertion, that the anterior and posterior roots coalesce in the gray matter, forming loops, the convexities of which are directed to the centre of the cord; and we have already stated our reasons (p. 259) for doubting the fibrous nature of the lines which these writers represent as radiating between the gray matter and the surface of the cord.

The posterior roots adhere to the posterior part of the antero-lateral column, and are doubtless closely connected with the posterior horns of gray matter. In separating the columns of the cord along the line of sequence of the fascicles of the posterior roots, we have always found these roots to remain with the antero-lateral columns, and to have little or no connexion with the posterior ones. We would therefore refer the origin of these nerves to the posterior horns of gray matter, and to the posterior part of the antero-lateral columns.

Of the Encephalic Nerves.—The arrangement of these nerves, originally proposed by Willis, although open to many objections, has nevertheless been so long adopted in this country and on the Continent, and is so constantly used by scientific as well as practical writers, that to abandon it would be productive of great inconvenience, and would be of no advantage, unless some other arrangement of unexceptionable kind could be substituted for it. In the absence of any such new mode of arrangement, we propose to adhere to that of Willis; at the same time remarking, that much of the imperfection of it is obviated by naming each pair of nerves from some prominent feature either of its function or its anatomical connexions.

Twelve pairs of nerves are found connected with the base of the encephalon. Five pairs have been so classed by Willis as to form two in his arrangement; three pairs being allotted to his eighth pair of nerves, and two to his seventh. Willis' arrangement, therefore, comprises the following nine pairs of nerves, which he enumerates in passing from the anterior to the posterior part of the base; the first pair, or *olfactory* nerves; the second pair, or *optic;* the third pair, *motores oculorum;* the fourth pair, *pathetici;* the fifth pair; the sixth pair, *abducentes oculum;* the seventh pair, including the *portio mollis* or *auditory* nerve, and the *portio dura* or *facial* nerve; the eighth pair, including the *glosso-pharyngeal*, the *pneumo-gastric*, and the *spinal accessory;* the ninth pair, or *hypoglossal.* Willis included among his encephalic nerves the first cervical nerve or *sub-occipital*, which he therefore numbered as the tenth pair.

As the cranium may be shewn to be composed of the elements of three vertebræ, it has been attempted to prove that among these nerves some may be classed with the vertebral or spinal nerves. The fifth is obviously of this kind, from its anatomical characters, namely, two roots: one small, ganglionless; the other large, ganglionic: and with the former, the analogue of the anterior spinal root, the third, fourth, and sixth nerves may be conjoined from their similarity in structure and distribution. Thus one *cranio-vertebral* nerve is formed, the anterior or motor root of which consists of the smaller portion of the fifth, the third, fourth, and sixth nerves, and the posterior or sensitive root of the larger portion of the fifth. A second cranio-vertebral nerve consists of the eighth pair, to which might be added the facial, contributing to its motor portion. A third is formed by the hypoglossal,* but the analogy, in the latter case, is certainly far from obvious.

How to determine the Function of a Nerve.—It has been stated, in a former chapter, that nerves evince special properties, depending on the connexions which they form at the periphery, or at the centre; that they may be divided into motor, sensitive, and, according to one view, excito-motor, according to the manner in which they respond to particular stimuli; and that fibres possessing each of these endowments may be bound together in a common sheath as one nerve. To determine with precision the office which each nerve performs, is a problem of great importance, not only from its bearing upon the physiology of the nervous centres, but from its great practical value in the diagnosis and treatment of disease.—(Introd. p. 28.)

The following are the means on which we should rely, in order to determine the function of a nerve.

* Müller's Physiology, by Baly, vol. i. p. 841.

First, *its anatomy in man.*—The origin by a double root denotes a double function. Its peripheral distribution, however, gives more valuable assistance. If distributed to muscles only, it clearly must be motor: if to sentient surfaces only, sensitive and perhaps excitor; if to both, motor, and sentient, or excito-motor.

Secondly, *its anatomy in animals.*—The comparison of the origin and distribution in the lower animals with those in man often throws light on the function, by confirming the result of anatomical investigation in the human subject, or by displaying either a peculiar development of the nerve, in reference to some special function proper to particular animals; or, on the other hand, the non-development of a nerve, or of a part of one, where some function may be deficient. The enormous development of a branch of the fifth nerve in animals with proboscides, or highly tactile snouts,—of a branch of the facial, where such an organ is very moveable,—the small size of the latter nerve where the muscles of the face are few, are instances quite in point.

Thirdly, *experiment* on animals just dead, or on those living.—The irritation of a motor nerve in an animal recently dead, causes contraction of the muscles to which it is distributed. The section of one in a living animal paralyses its muscles; but irritation of the portion below the section causes contraction of those muscles which that segment of the nerve supplies. The simplest way of applying a stimulus for experimental purposes, is by passing a galvanic current from a small battery. If the current be directed through a nerve so that it shall pass along the smallest portion of it, by placing one pole on one side of it, and the other on the opposite, but a little lower down or higher up, we may gain a strong indication of the motor power of the nerve, if contractions are thereby excited. This indication becomes certain if the same effect be produced by galvanizing the nerve in this way, after it has been separated from all connexion with the spinal cord or brain. Such an experiment on a sensitive nerve would produce no motor effect. Matteucci has shewn, that to produce the motor effect in a motor nerve, the current must pass *along* some portion of the nerve-fibre, however small; and that a current directed precisely at right angles to the fibres will not excite nervous power.*

MM. Longet and Matteucci affirm, that a motor nerve may be distinguished from a compound one by the different effect of opening or closing an electric current on each under certain circum-

* See an account of Matteucci's observations on the different effects of electricity on nerves, in the appendix to this chapter.

stances. It had already been ascertained by Lehot, Bellingeri, Nobili, and Marianini, that compound nerves, the sciatic for instance, are at first excited equally on closing and on opening the electric circuit, whether the current be direct (*i. e.* from the brain or cord to the nerves), or inverse (from the nerves to the brain or cord); but after a time they are excitable, as shewn by the contraction of the muscles below the point of the nerve stimulated, only on *closing the direct current* or *opening the inverse.* With a purely motor nerve, however, such as the anterior root of a spinal nerve, a different result is obtained; inasmuch as the contractions of the muscles can only be excited *on opening the direct current* or *closing the inverse.**

Sometimes we find that, if the trunk of a nerve be divided at some distance from its origin, irritation of the central segment will excite contractions, whilst that of the peripher alone will fail to do so. Such a nerve has been called an *excitor;* for it causes muscular movement, not by its direct influence upon muscles, but by exciting the centre, which in its turn stimulates *motor* nerves arising from it. We judge a nerve to be sensitive, if, when irritated in man or the lower animals during life, a peculiar sensation or pain be excited; or if section of it destroys the sensibility of the parts to which it is distributed.

Fourthly. *Clinical observation* furnishes most valuable opportunities of testing the true function of nerves. We observe a particular form of paralysis, and we inquire what nerve is diseased; we find pain felt in particular regions, and we ascertain that this is in consequence of a morbid state of particular nerves; certain functions are impaired or suspended, if certain nerves be affected with disease. A woman, lately in King's College Hospital, had a singular train of symptoms, which were at first referred to hysteria. However, in a little time they became so confirmed, that no doubt could be entertained of organic lesion. There were ptosis of the upper lids,—paralysis of the muscles of the eyeball supplied by the third nerve,—paralysis of the pharynx, so that the power of deglutition was destroyed,—paralysis of the trapezii muscles, and of those on the back of the neck,—a great feebleness of voice. She died like one asphyxiated. After death, the following nerves were found involved in a thickened neurilemma, with altered nerve tubes,—the third pair, the fourth pair on the left side, the glossopharyngeal, the vagus, the spinal accessory; each of

* Matteucci et Longet, sur la relation qui existe entre le sens du courant électrique et les contractions musculaires dues à ce courant. Paris, 1844.

which contribute more or less to supply with nerves the parts paralysed.

Functions of the Roots of Spinal Nerves.—The application of anatomical investigation, and of experiment, to determine the functions of the anterior and posterior roots of spinal nerves respectively, was the first important step towards a right understanding in the physiology of the nervous system. This was undoubtedly taken by Sir C. Bell; and, although there were other labourers in the same field not unworthy claimants of some share in the merit of this important investigation, it cannot be denied that the endowments of the roots were discovered by Bell.

The original experiments of Bell, in which he was assisted by the late Mr. John Shaw, consisted in laying open the spinal canal in rabbits, and irritating or dividing the roots of the spinal nerves. Bell distinctly affirmed that irritation of the anterior roots caused muscular movement, and that the posterior roots might be irritated without giving rise to any muscular action. Destruction of the posterior roots did not impair the voluntary power over the muscles. Hence it was inferred that the anterior roots were motor, and the posterior roots not motor; but, from the violence of the operation, and the pain produced in performing it, the experiments having been tried on rabbits, it was impossible to determine what degree of sensibility remained in parts supplied from the divided roots.

Numerous subsequent experimenters arrived at similar results to those of Bell; but no one obtained such satisfactory conclusions as Müller, who adopted the expedient of experimenting on frogs instead of mammalia, with which latter the experiments involved the necessity of a tedious and painful operation, and much bloodshed. In frogs, on the contrary, from the great width of the lower part of the spinal canal, the roots of the nerves can be exposed with facility, and their excitability lasts sufficiently long to yield every result. These experiments we have repeated frequently, with results precisely similar to those which Müller obtained.

In the experiments on frogs, irritation, mechanical or galvanic, of the anterior root always provokes muscular contraction. No such effect follows irritation of the posterior root. Section of the anterior root causes paralysis of motion; that of the posterior, paralysis of sensation. This latter effect is evinced by the utter insensibility to pain shewn on pinching a toe, whilst in the limb in which the posterior root is entire such an irritation is evidently acutely felt. If the anterior roots of the nerves to the lower extremity be cut on one side, and the posterior roots on the other, voluntary power without sensation will remain in the latter, and sensation without voluntary power in the former.

Valentin, Seubert, Panizza, and Longet have performed similar experiments upon mammiferous animals with precisely the same effects.

The conclusion to be derived from these experiments is as follows: *that the anterior root of each spinal nerve is motor, and the posterior sensitive.*

Comparative anatomy confirms this conclusion, by shewing that a similar arrangement of the spinal roots prevails among all classes of vertebrate animals, and that, if in any particular class of animals either the motor or sensitive power predominate, there is in correspondence with it a marked development of the anterior or posterior roots; and the frequent occurrence of paralysis of sensation and motion, as a consequence of disease within the spinal canal, also tends to the same inference.

Magendie affirms that the anterior root is slightly sensitive, owing, as Kronenburg has shewn, to an anastomotic filament which it derives from the posterior root.

Functions of the Spinal Cord.— Since nerves of sensation and motion have their origin from the cord, it cannot be doubted that this organ is the medium for the reception and propagation, first, of sensitive impressions made upon those surfaces on which its nerves are distributed, and secondly, of those impulses which are the ordinary excitants of muscular movements.

Experiments and clinical observation, however, shew that sensation and *voluntary* motion are not connected with, or dependent on, the spinal cord *alone.* If the connexion of this organ with the encephalon be perfect, and uninterrupted by any solution of continuity, morbid deposit in it, or morbid growth causing compression, then the essential condition for the full play of the nervous force, whether for sensation or voluntary motion, is fulfilled. But if the cord be severed just below the plane of the occipital foramen as when an animal is pithed, all voluntary power over the parts supplied by spinal nerves ceases, and all sensation in those parts disappears at the same time. Here the cord itself is uninjured; but its continuity with the encephalon is destroyed.

In cases of injury to the vertebral column, causing fracture and displacement of the vertebræ, and destruction of the cord, the parts supplied from that portion of the cord which is below the seat of injury are paralysed as regards voluntary motion and sensation.

The higher the seat of injury, the more extensive will be the paralysis. A man who has received extensive injury of the spinal cord in the neck, is like a living head and a dead trunk,—dead to its own sensations, and to all voluntary control over its movements.

Similar remarks may be made respecting those cases in which disease, or compression of the cord by some intra-spinal growth, has interruped its continuity in some region. The extent of the paralysed parts always affords a correct indication of the seat of the solution of continuity.

If the spinal cord be divided partially in the transverse direction there will be paralysis of parts *on the same side* with the injury inflicted. A longitudinal section of the cord along the median line does not cause any paralysis; a temporary disturbance of its functions, however, ensues, which soon subsides.

So long, then, as the spinal cord and encephalon are continuous and in their normal state, the former organ must be regarded as specially adapted to receive and propagate sensitive impressions from the trunk and extremities, or to convey the stimulus of volition to their muscular nerves.

There is nothing, however, in these facts to denote that the spinal cord does not share, in some degree, in the function of sensation and voluntary motion. All that we are justified in inferring from them is, that the union of the encephalon with the spinal cord is necessary for voluntary motion and for sensation.

Indeed, the recent discovery of the *amphioxus lanceolatus,* a small fish found in the Archipelago, makes it probable that voluntary motion and sensation may exist where there is a well-developed spinal cord, the anterior extremity of which tapers to a fine point, and is far from exhibiting the ordinary characteristics even of a brain so inferior in organization as that of fishes.

In most instances where the spinal cord has been divided, whether by design or accident, it has been found that, although the will cannot move the paralysed parts, movements do occur in them of which the individual is unconscious, and which he is wholly unable to prevent. These take place sometimes as if spontaneously, at other times as the effect of the application of a stimulus to some surface supplied by spinal nerves. The apparently spontaneous movements frequently resemble voluntary actions so closely, that it is almost impossible to distinguish them.

These phenomena occur in all classes of animals, warm-blooded

* Goodsir, in Ed. Philos. Transactions, and Cyclop. of Anat. vol. iii. p. 615.

as well as cold-blooded. In the latter, however, they are much more marked; the nervous force endures much longer in these animals than in the higher classes of mammalia and birds, just as we have already seen that the muscular power does, although we have no reason to suppose that either force is more energetic, because it is more enduring. On this account, cold-blooded animals must be selected for exhibiting the phenomena; and accordingly hosts of frogs, salamanders, snakes, turtles, and fishes have fallen a prey to the experimental researches of the numerous physiologists who have devoted themselves to these investigations.

The following experiments serve to illustrate these actions:

If a frog be pithed by dividing the spinal cord between the occipital hole and the first vertebra, an universal convulsion takes place while the knife is passing through the nervous centre. This, however, quickly subsides; and, if the animal be placed on a table, he will assume his ordinary position of rest. In some exceptional cases, however, frequent combined movements of the lower extremities will take place for a longer or shorter time after the operation. When all such disturbance has ceased, the animal remains perfectly quiet, and as if in repose, nor does there appear to be the slightest expression of pain or suffering. He is quite unable to move by any voluntary effort. However one may try to frighten him, he remains in the same place and posture. If now a toe be pinched, instantly the limb is drawn up, or he seems to push away the irritating agent, and then draws up the leg again into its old position. Sometimes a stimulus of this kind causes both limbs to be violently moved backwards. A similar movement follows stimulation of the anus. If the skin be pinched at any part, some neighbouring muscle or muscles will be thrown into action. Irritation of the anterior extremities will occasion movements in them; but it is worthy of note, that these movements are seldom so energetic as those of the lower extremities.

It is not out of place to state here, that phenomena of this kind are not confined to the trunk and extremities which are supplied by spinal nerves only. The head and face with which the encephalon remains in connexion exhibit similar actions. The slightest touch to the margin of either eyelid, or to the surface of the conjunctiva, causes instantaneous winking; the attempt to depress the lower jaw, for the purpose of opening the mouth, is resisted; and the act of deglutition is provoked by applying a mechanical stimulus to the back of the throat.

The stimuli which excite these movements are those ordinary ones which are capable of calling nervous power in to play, such as mechanical irritation, heat, cold, galvanism, chemical irritants.

There can be no grounds for supposing that the will has anything to do with these movements. An animal pithed, which is to all intents and purposes in the same condition as one decapitated, shews no sign of voluntary action, excepting perhaps for a short time after the operation, whilst the irritation caused by the division of the cord remains. He maintains one and the same position, without evincing any sign of sense or motion, unless a stimulus be applied to some part of the surface; and, after the movement which such a stimulus excited has ceased, he resumes the same state of inactivity.

Comparing this state of a pithed or decapitated animal with the phenomena which we know to take place in the human subject in effect of particular forms of accident or disease, it is impossible to regard these actions in any other light than as involuntary ones. To refer once more to such a case as that cited in a former paragraph, when, from the destruction of the cervical part of the cord, the trunk appears as if dead, while the head lives, we find in many instances, if the stunning effect have not been too great, that similar motions to those described in the frog may be produced by the application of mechanical or other stimuli to the surface. Tickling the soles of the feet causes movements of the lower extremities: the introduction of a catheter into the urethra, which is not felt by the patient, excites the penis to erection. Over these acts not only have the patients no control, but they are absolutely unconscious of their occurrence, as well as of the application of the stimuli by which they were provoked. It is plain, then, that these movements take place without the concurrence or even the cognizance of the *mind*, whether as the recipient of stimuli, or as the source of voluntary impulses.

In hemiplegia, the result of diseased brain, when the paralysis is complete, the influence of the will over the paralysed side is altogether cut off. In such cases, movements may be excited in the palsied leg—very rarely in the arm—by stimuli applied to the sole of the foot, or elsewhere; and we often astonish the patient himself, who expresses his utter inability, by any effort of his will, to move his leg, by exciting active movement of it on touching the sole of the foot very lightly with a feather. It is proper to add, that there is much variety as regards the extent to which these actions take place in hemiplegic cases, owing to causes which are not yet fully understood. Still, they do occur in a large proportion of instances, and in the most marked way. In most of the cases of hemiplegia the surface retains its sensibility; but in most of those of paraplegia sensibility is much diminished or completely destroyed.

In the anencephalic fœtus, in which all the encephalon but part of the medulla oblongata is wanting by congenital defect, actions take place in obedience to stimuli propagated to the cord from some surface, or applied directly to it; but no movements are seen which can be supposed to originate in an effort of the will, nor is there any proof of the existence of sensibility.

Other facts may be adduced in evidence of the involuntary nature of these movements.

It is remarkable that actions of this kind will continue to be manifested after decapitation, not only in the trunk, but also in segments of it with which a portion of the spinal cord remains in connexion. If the body of a snake or an eel be divided into several segments, each one will exhibit movements for some time, upon the application of a stimulus. The same thing may be observed in frogs, salamanders, turtles, and other cold-blooded creatures. In birds and mammalia, however, they are less conspicuous, because in them the nervous power is so soon extinct.

These facts suggest an obvious comparison between the spinal cord of vertebrate animals and the abdominal ganglionic chain of articulate invertebrata. In the latter, each segment of the body has its proper ganglionic centres, and is, therefore, to a certain extent independent of the rest. Every schoolboy has witnessed the writhings of an earthworm, which his mischievous propensity has prompted him to divide into several pieces. Movements will continue in each piece so long as the irritation produced by the subdivision remains; and, after that has ceased, movements may be excited in any segment by stimulating its surface. These movements seem precisely analogous to those which may be excited in the subdivisions of the trunk of a vertebrate animal. The spinal cord, then, may be viewed as one continuous centre, made up of a number of segments fused together at their extremities. In the articulate ganglionic chain the centres of the segments remain distinct, although connected by fibres which pass from one to the other.

When the spinal cord is divided about its middle, a remarkable difference may be noticed in the effects of irritation on the anterior and the posterior segment, as shewn in some of Flouren's experiments. When the anterior segment (that which still retains its connexion with the brain) is irritated, not only are movements of the anterior extremities produced, but the animal evinces unequivocal signs of pain: but, when the posterior segment is irritated, the animal seems not only insensible to pain, but unconscious even of the movements that have been excited in the posterior extremities.

Nothing can be more conclusive than such an experiment, in illustration of the fact that connexion with the encephalon is necessary to sensation: and that movements, not only without volition, but even without consciousness, may be excited by stimulating the posterior segments.

Direct irritation of the spinal cord is capable of exciting these movements as much as when the stimulus is applied to the skin.

When the spinal cord is removed, all these motions cease; no movement of any kind, voluntary or involuntary, can then be excited, except by directly stimulating the muscles, or the motor nerves by which the muscles are supplied. Division of all the roots of the nerves at their emergence from the cord produces precisely the same effect. Under such circumstances no motion can be excited by stimulation of the surface, nor by stimulation of the cord itself; and this fact may be regarded as an unequivocal proof that the nerves, in ordinary actions, are propagators of the change produced by impressions to or from the centres; and that in the physical nervous actions the stimulus acts not from one nerve to another directly, but through the afferent nerve upon the centre, by which the motor nerve is excited.

From these details we may draw the following conclusions:—1, that the spinal cord, (we use the term in its simple anatomical sense,—the intra-spinal nervous mass), *in union with the brain,* is the instrument of sensation and voluntary motion to the trunk and extremities; 2, that the spinal cord may be the medium for the excitation of movements, *independently* of volition or sensation, either by direct irritation of its substance, or by the influence of a stimulus conveyed to it from some surface of the trunk or extremities by its nerves distributed upon that surface.

This latter office of the cord, although recognized by Whytt, Prochaska, Blane, and Flourens, had not attracted all the notice which its great importance merits, until the reseaches of Dr. Marshall Hall and Professor Müller drew attention to them; and to these physiologists, but especially to the former, much praise is due for the zealous and efficient manner in which they have investigated the subject.

The class of actions which take place in virtue of this power of the cord are so independent of all mental influence, and so purely physical in their cause, as well as in their nature, being provoked by a physical stimulus, and consisting essentially in a physical change in the centre, as well as in its afferent and efferent nerves, that they may be distinguished from those of volition and sensation, in which the mind has a necessary share, by being designated "physical." It has been already stated, that Dr. Marshall Hall uses the not unobjectionable title of "excito-motory" in reference to these actions.

In general, when a stimulus is applied to the spinal cord, the actions which are excited by it are confined to a part which derives its nerves from that segment of the cord on which the stimulus falls. In some instances, however, parts supplied from other and even distant segments are thrown into action. Thus irritation of one leg will cause movements of one or both of the upper extremities; the introduction of a catheter into the urethra will sometimes cause forcible contractions of the muscles of all the limbs. No doubt these effects are due to the extension of the irritation in the cord beyond the point first stimulated; and they may be regarded as proofs that that peculiar state of physical change which nervous irritation can excite in a centre may be propagated in the spinal cord, upwards, downwards, or sideways from the seat of the primary stimulation.

Disease affords some striking instances in confirmation of this remark.

A wound in the sole of the foot, or the ball of the thumb, or in some other situation favourable to the maintenance of prolonged irritation, is capable of exciting a particular region of the cord, from which the state of excitement spreads so as to involve not only the whole cord, but part of the medulla oblongata also; and in this state a large proportion of the motor nerves participate, so as to induce tonic contraction of the muscles they supply. This is the rationale of the development of that fearful malady called *tetanus*. It consists not in an inflammatory affection of the cord, or of its membranes, nor in congestion of them, but simply in a state of prolonged physical excitement, the natural polar force of the centre being greatly exalted, and kept so by the constant irritation propagated to it by the nerves of the wounded part.

In cases of paraplegia from disease of the spinal cord, even when the paralysis of sensation and of motion is complete, patients are tormented with involuntary movements of the lower extremities at night, which not only prevent sleep, but occasion considerable pain and distress. Thus, parts which in their quiescent state are insensible, become painful in the state of excitement. The cause of this is no doubt to be found in a periodical exacerbation of the primary disease of the cord, and the extension of the state of excitement from the seat of the lesion to the whole cord; to that portion which is in connexion with the brain, as well as to that which is below the lesion.

The rigid and contracted state of the muscles of paralysed limbs, which frequently accompanies red softening of the brain, arises from the propagation of the excited state of the diseased part of the brain to that portion of the spinal cord which is connected with it, and from which the nerves of the paralysed parts arise. These nerves likewise participate in the irritation of the cord, and thus keep the muscles in a continual state of active contraction. There is no organic lesion of the cord in these cases; its state of excitement is dependent on the cerebral irritation.

The convulsions of epilepsy arise from a similar cause, namely, irritation of the brain, involving the whole or a part of the spinal cord, and the nerves arising from it. In many instances the convulsions are limited to one half of the body: in such cases there is generally lesion of the brain on one side, and the cerebral excitement is propagated only to one half (the opposite) of the cord.

Some substances exert a peculiar influence upon the spinal cord, and throw it into a state of considerable polar excitement. Strychnine is the most energetic substance of this class. If a certain quantity of this drug be injected into the blood, or taken into the stomach of an animal, a state of general tetanus will quickly ensue, sensibility remaining unimpaired. The slightest touch upon any part of the surface, even a breath of wind blown upon it, will cause a general or partial convulsive movement. The whole extent of the cord is thrown into this polar state, and even the medulla oblongata is involved in it; whence the closed jaws, the spasmodic state of the facial muscles, the difficult deglutition. In this remarkable state of excitement, it is curious to observe that the spinal cord is perfectly natural in point of structure, as far as our means of observation enable us to judge. We have examined some spinal cords of animals which have died exhausted by the effects of the strychnine, but have always found the nerve-tubes and other elements of the cord exhibiting their natural appearance.

Opium is capable of creating a similar state of polarity in the cord. This is most conspicuous in cold-blooded animals; but no doubt it produces, in a much less degree, a similar effect in the warm-blooded classes. Hence there is an objection to the use of opium in large doses in cases of tetanus; and experience has shewn its utter inefficacy when administered to a large amount.

This polar state of the cord, at least of a part of it, is sometimes developed naturally. The most remarkable example of this with which we are acquainted is in the case of the male frog, in the spring of the year, the season of copulation; the thumb on each hand becoming at this season considerably enlarged, as is well known to naturalists. This enlargement is caused principally by a considerable development of the papillary structure of the skin which covers it, so that large papillæ are formed all over it. A male frog at this season has an irresistible propensity to cling to any object by seizing it between his anterior extremities. It is in this way he seizes upon and clings to the female, fixing his thumbs to each side of her abdomen, and remaining there for weeks, until the ova have been completely expelled. An effort of the will alone could not keep up such a grasp uninterruptedly for so long a time; yet so firm is the hold, that it can with difficulty be relaxed. Whatever is brought in the way of the thumbs will be caught by the forcible contraction of the anterior limbs; and hence we often find frogs clinging blindly to a piece of wood, or a dead fish, or some other substance which they may chance to meet with. If the finger be placed between the anterior extremities, they will grasp it firmly; nor will they relax their grasp until they are separated by force. If the animal be decapitated whilst the finger is within the grasp of its anterior extremities, they still continue to hold on firmly. The posterior half of the body may be cut away, and yet the anterior extremities will still cling to the finger; but immediately that segment of the cord from which the anterior extremities derive their nerves has been removed, all their motion ceases. This curious instinct, then, of the male frog, which naturalists have long noticed, is evidently connected with an exalted polarity of the cord, which is most manifest in the anterior extremities by reason of the enlargement of the thumb. It only exists during the period of sexual excitement; for at other periods the excitability of the anterior extremities is considerably less than that of the posterior.

Nothing seems to control this polar state of the cord so effectually as cold. Ice applied along the spine, or the cold douche, may be frequently employed with great advantage in cases of muscular disturbance dependent on this polar state of the cord. We know of no substance which, when introduced into the blood, effectually calms this excited state. Conium and belladonna have been, in our hands, very useful in relieving the cramps and startings in paraplegic cases. We have seen no marked benefit from hydrocyanic acid, although we have administered it freely: on the contrary, we fear that both it and the two former substances might, if given in large doses, have the contrary effect, and increase the polarity of the cord. Certain it is, that animals poisoned by large doses of these drugs always die in a state of general convulsion, and that in the instances where they have acted as poisons on the human subject, general convulsions have come on a longer or shorter time before death.

Functions of the Columns of the Cord.—Having so far determined the functions of the entire cord, the next question which demands our attention is, whether its columns have special functions, in accordance with those of the separate roots of the nerves. Could it be proved that the anterior or motor roots were exclusively connected with the antero-lateral columns, and that the posterior or sensitive ones arose exclusively from the posterior columns, then there would be good anatomical grounds for the doctrine so long erroneously prevalent, that the functions of these columns coincided with those of the roots, that the posterior columns were sensitive, and the anterior motor: but nothing is more certain, than that both roots are connected with the antero-lateral columns; and it is a matter of some doubt, whether the posterior roots have any connexion at all with the posterior columns. Hence, all that anatomy warrants us in stating is, that the antero-lateral columns are probably compound in function, both motor and sensitive. Respecting the office of the posterior columns, little can be said. Are they sensitive? Were they so, it might be expected that they would exhibit an obvious enlargement at the situations which correspond to the origins of the largest sensitive nerves; but it is remarkable that the posterior columns exhibit little variation of size throughout the entire length of the cord. And it is not likely they can be motor, inasmuch as the apparent origin of the motor roots is so distinctly remote from them.

Comparative anatomy throws no light on this question. New and careful researches are much needed to determine the development of the posterior columns, and the exact relation which the posterior roots bear to them in different classes of animals.

Nor do we derive much positive knowledge from the researches of the morbid anatomist. Cases, indeed, are on record, which shew that disease of the posterior columns does not necessarily destroy sensibility; that perfect sensibility is compatible with total destruction of the posterior columns in some particular region, the posterior roots remaining intact: and others have occurred in which sensibility has been impaired or destroyed, while the posterior columns remained perfectly healthy. In a remarkable case, related by Dr. Webster, there was complete paralysis of motion in the lower extremities, but sensibility remained;* yet there was complete destruction of the posterior columns in the lower part of the cervical region. Similar cases have been put on record by Mr. Stanley and by Dr. W. Budd. Dr. Nasse, of Bonn, refers to several cases of the same kind, observed by himself or others.† We have ourselves seen two cases in which the prominent symptom was great impairment of the motor power without injury to the sensitive; yet the seat of organic lesion in both was in the posterior columns of the cord. Such a case as that of Dr. Webster's appears to us to be conclusive, so far as the following proposition extends, namely, that sensation may be enjoyed in the inferior extremities *independently of the posterior columns;* and that, even if those columns be sensitive, there must be some other channel for the transmission of sensitive impressions besides them.

We are not aware of any well-observed case in which the motor power persisted after extensive lesion of the antero-lateral columns; on the contrary, we believe it may be laid down as the general rule, that lesion of those columns always impairs both the motor and the sensitive functions to an extent proportionate to the amount of morbid structure.

Pathological observations, then, appear to warrant the conclusion that the antero-lateral columns are compound in function, both sensitive and motor; but they do not justify us in attributing sensitive power to the posterior columns.

Direct experiments on the anterior and posterior columns of the cord are surrounded by difficulties, which embarrass the experimenter, and weaken the force of his inferences. The depth at which the cord is situate in most vertebrate animals, its extreme excitability, the intimate connexion of its various columns with each other, so that one can scarcely be irritated without the participation of the others, the proximity of the roots of its nerves to each other, and the difficulty of irritating any portion of the cord itself without affecting either the anterior or the posterior roots, are great

* Med. Chir. Trans., vol. xxvi.

† Untersuchungen zur Physiologie und Pathologie. Bonn, 1835-36.

impediments to accurate experiments, and sufficiently explain the discrepancies which are apparent in the results of the various experiments which have been published. Moreover, the resultant phenomena, after experiments of this kind, are extremely difficult of interpretation, especially with reference to sensation. "The gradations of sensibility," remarks Dr. Nasse, "are almost imperceptible; the shades are so delicately and so intimately blended, that every attempt to determine the line of transition proves inadequate. There is a great deal of truth in an expression of Calmeil, that it is much easier to appreciate a hemiparalysis of motion than a hemiparalysis of sensation. If the anterior fasciculi of the cord possesses sensibility, but only in a slight degree, the mere opening of the vertebral canal and laying bare the cord must cause such a degree of pain as would weaken or destroy the manifestations of sensibility in the anterior fasciculi. This has not been sufficiently attended to by experimenters. Again, the practice of first irritating the posterior fasciculi, and afterwards the anterior, must have had considerable effect in producing the same alteration. It is plain that, in this way, the relations which the anterior fasciculi bear to sensation must be greatly obscured; yet, with the exception of some few experiments, this has been the order of proceeding generally adopted."*

All those who have made experiments with the view of ascertaining the function of the columns of the cord, agree in stating that irritation of the anterior columns was attended with more or less movement. The results of stimulation of the posterior columns, however, have been differently stated by various observers: many found that it was attended with the excitation of motion; and others, that the least irritation of the posterior columns excited pain. M. Longet, who is among the latest experimenters on this subject, observes, that motions result from irritation of the posterior columns only when the experiment has been made immediately after the transverse division of the cord, and he refers such motions to the excitability of the cord itself. After a little time, however, this subsides; and then M. Longet has been able to pass the galvanic current through each or both of the posterior columns, without exciting any motions when the lower segment of the cord was acted upon, but causing pain, as evinced by loud cries and writhing of the body, when the upper segment was tried. Dr. Baly's experiments on tortoises showed that movements might be excited whether the

* Loc. cit.; quoted from an abstract in the Brit. and For. Med. Review, vol. iv.

anterior or posterior columns were irritated,* much stronger motions being excited by the posterior than by the anterior columns.

It is clear, then, that we must not draw any other conclusion from experiment than that the antero-lateral columns appear to be motor in their function. Respecting their sensitive power we gain no information from this source; and it must be confessed that our knowledge is no more advanced by it as regards the posterior columns.

We are much disposed to think that the antero-lateral columns are the centres of the main actions of the cord, whether mental or physical. Both roots of the nerves are connected with these columns, and therefore fibres of sensation and of motion must be found in them. These columns are always proportionate to the nerves which arise from them: they enlarge when the nerves are large, and contract when the nerves diminish in size. The posterior columns, on the other hand, are of uniform dimension throughout nearly the entire length of the cord, although the posterior roots of the nerves exhibit considerable difference in point of size in different regions.

We venture to suggest that the posterior columns may have a function different from any hitherto assigned to them. They may be in part commissural between the various segments of the cord, and in part subservient to the function of the cerebellum in regulating and co-ordinating the movements necessary for perfect locomotion.

The analogy of the brain, in which the various segments are connected by longitudinal commissures, suggests the probable existence of fibres similar in office for the spinal cord. If we admit such fibres to be necessary to ensure harmony of action between the several segments of the encephalon, there are as good grounds for supposing their existence in the cord, which in reality may be regarded as consisting of a number of ganglia, each a centre of innervation to its proper segment of the body, and therefore requiring some special connecting fibres to secure consentaneous action with the rest.

The attribute of locomotive power rests upon the connexion of the posterior columns with the cerebellum, and the probable influence of that organ over locomotion. If the cerebellum be the regulator of locomotive actions, it seems reasonable to suppose that those columns of the cord which mainly pass into it, should enjoy a similar function; that, as they are the principal medium through which the cerebellum is brought into connexion with the cord, it

* See his translation of Müller's Physiology, Second Edit., p. 796*.

must be through their constituent fibres that the cerebellum exerts its influence on the nerves of the lower extremities, and of other parts concerned in the locomotive function.

The nearly uniform size of the posterior columns in the different regions of the cord has been already remarked as unfavourable to their being channels of sensation. But this anatomical fact may be adduced as a good argument in support of the hypothesis which we are now discussing. It is worthy of notice that these columns experience no marked diminution in size until the large sacral nerves, which furnish the principal nerves of the lower extremities, begin to come off.

In examining a transverse section of the lumbar region of the cord we observe a great predominance of its central gray matter; the posterior columns appear large, and the antero-lateral columns inadequate in proportion to the large roots of nerves which emerge from it. Now, an analysis of the locomotive actions renders it highly probable, that they are partly of a volitional character and partly dependent on the inherent power of that segment of the cord from which the lower extremities derive ther nerves. In progression there are two objects to be attained,—to support the centre of gravity of the body, and to propel it onward; the former object requiring, first, that the muscles of the lower extremities, the pillars of support to the trunk, should be well contracted, in a degree proportionate to the weight they have to sustain. Those actions by which the trunk is balanced upon the limbs, and by which the movements of progression are effected, are subsequently called into play through mental influence. The contraction of the muscles of the limbs seems well provided for in an arrangement for the development of nervous power by a stimulus propagated *to* the centre. This stimulus is afforded by the application of the soles of the feet to the ground; it is therefore proportionate to the weight which presses them downwards. It is well known that physical nervous actions are more developed in the lower than the upper extremities, and the surface of the sole of the foot is well adapted for the reception of sensitive impressions. No object can be assigned for this peculiarity, unless it have reference to the locomotive actions; and the great development of the vesicular matter in this region betokens the frequent and energetic evolution of the nervous force. All the structural arrangements necessary for this purpose are found in the antero-lateral columns. The posterior columns come into play in balancing the trunk, and in harmonizing its movements with those of the lower extremities.

Experiment, while it fails to elucidate the function of the posterior column, exhibits nothing in opposition to the views we have expressed. It is not to be expected that commissural and co-ordinating fibres should react with stimuli similarly to fibres of voluntary motion.

We think that the phenomena of disease may be referred to in support of our view. In many cases where the principal symptom has been a gradually increasing difficulty of walking, the posterior columns have been the seat of disease. We may notice two kinds of paralysis of motion, distinguished respectively by impairment or loss of voluntary motion, and of the power of co-ordinating movements. In the latter form, while the voluntary powers are considerable, the patient walks with great difficulty, and a gait so tottering that his centre of gravity is easily displaced. These cases are generally of the most chronic kind, and many of them go on from day to day without any increase of the disease or improvement in their condition. In two examples of this variety we ventured to predict disease of the posterior columns of the cord: and this was found to exist on a post-mortem inspection. All cases on record, which we have had the opportunity of examining, in which the posterior columns were the seat of disease, began by evincing more or less disturbance of the locomotive powers; and it seems to us that the degree to which sensibility may become affected will greatly depend upon the extent to which the *posterior roots* of the nerves are involved in the disease.

The hypothesis, then, which we are most disposed to adopt, is the following:—That *the antero-lateral columns of the spinal cord with the gray matter* are, in connexion with the brain, the recipients of sensitive impressions and volitional impulses, and that they are the centres of the independent or physical nervous actions of the cord; and that *the posterior columns* propagate the influence of that part of the encephalon which combines with the nerves of volition to regulate the locomotive powers, and serve as commissures in harmonizing the actions of the several segments of the cord.

What is the *mechanism* of these actions of the spinal cord—mental, physical, locomotive? This is a problem of the highest interest, bearing upon the mechanism by which nervous power developed in any nervous centre, as well as in the cord, is capable of affecting peripheral parts; and it is on that account well deserving the most patient investigation.

We assume, as necessary postulates, preliminary to the discussion of this question, the two following propositions:—1. That the brain, or some part of it, is the sensorium commune; or, in other words, that mental nervous actions (acts of volition and sensation) cannot take place without the brain. 2. That the vesicular is the truly dynamic nervous matter, the source of all nervous power.*

The following hypothesis have been proposed in explanation of these actions.

1. The various muscles and sentient surfaces of the body are connected with the brain by nerve-fibres, which pass from the one to the other. Those fibres destined for, or proceeding from, the trunk to the brain, pass along the spinal cord, so that that organ is in great part no more than a bundle of nerve-fibres going to and from the brain. These fibres are specially for sensation and voluntary motion.

But, in addition to these, there is another class of fibres proper to the spinal cord and to its intra-cranial continuation, which form a connexion with the gray matter of the cord. Of these fibres, some are afferent or incident, others efferent or reflex, and these two kinds have an immediate but unknown relation to each other, so

* The first of these postulates will be considered farther on in this chapter. The second appears to us to have a sufficiently firm foundation to warrant us in assuming its correctness, for the sake of arguing the important question referred to in the text. We shall state briefly here the proofs that the association of the vesicular and fibrous matter is necessary to the development of nervous force.

1. Nerves, when separated for a time from the nervous centre, lose all power of stimulating their muscles to contraction. No irritation, mechanical or electrical, is sufficient to excite them. If a nerve be divided some distance from the centre, the peripheral portion will, after a time, waste, and lose all power of developing nervous force; but the central portion, which remains in connexion with the centre, retains its nutrition and its vital properties unimpaired.

2. All nervous centres contain vesicular matter, with which nervous fibre freely intermix.

3. The power of a nervous centre appears to be proportionate to the quantity of its vesicular matter. This is well exemplified in the cerebral convolutions, the vesicular surface of which is always in the direct proportion of the development of mental power; or, in general terms, *the gray matter increases in the exact ratio of the nervous energy.* (Grainger).

4. All nerves appear to rise from vesicular matter. Stilling represents special accumulations of vesicular matter at the origins of the nerves of the medulla oblongata.

5. Nerves, whose power is exalted for some special purpose, have an increased quantity of gray matter at their origin, of which the electric lobe in the torpedo, connected with the origins of the fifth and eighth pairs of nerves, is an extraordinary instance.—See Mr. Grainger's excellent work on the spinal cord, pp. 18-21.

that each afferent nerve has its proper efferent one, the former being *excitor*, the latter *motor*. The aggregate of these fibres together with the gray matter constitutes the *true spinal cord* of Dr. Marshall Hall, which is not limited to the spinal canal, but passes up into the cranium as far as the crura cerebri. These fibres are quite independent of those of sensation and volition, and of the sensorium commune. Although bound up with sensitive and motor fibres, they are not affected by them, and they maintain their separate course in the nerves as well as in the centres. Such is the hypothesis of an *excito-motory system of nerves*, and of a *true spinal cord*, the centre of all *physical* nervous actions, which has been proposed and most ably advocated by Dr. Marshall Hall.

2. The fibres of sensation and volition proceed to and from some part or parts of the intra-cranial mass. Those which are distributed to the trunk pass along the spinal cord, separating from it with the various roots of the nerves, and in their course within the spine they mingle more or less with the gray matter. There are no other fibres but these (save the commissural), and they are sufficient to manifest the physical as well as the mental acts. Nerves of sensation are capable of exciting nerves of motion which are in their vicinity; and they may produce this effect even when the spinal cord has been severed from the brain, for their relation to the gray matter of the cord is such that their state of excitement is readily conveyed to it. This explanation tallies with the views of Whytt, Prochaska, and the other physiologists who had recognized the existence of a class of actions produced by the influence of sensitive upon motor nerves.

3. According to a third hypothesis, it is assumed that all the spinal and encephalic nerves, of whatever function, are implanted in the gray matter of the segments of the cerebro-spinal centre with which they are severally connected, and do not pass beyond them. The segments are connected with each other through the continuity of the gray matter from one to another, and through the medium of commissural fibres which pass between them. Through these means, motor or sensitive impulses are propagated from segment to segment; and a stimulus conveyed to any segment from the periphery may either simultaneously affect the brain and cause a sensation, or be reflected upon the motor nerves of that segment and stimulate their muscles to contract.

The first hypothesis, which assumes the existence of a distinct series of incident and reflex nerves for the physical nervous action, offers a very beautiful explanation of those cases in which, while sensation is entirely destroyed, movements may yet be excited without the consciousness of the individual. In such cases it is supposed that the fibres of sensation and volition are alone paralysed, but that those of the true spinal cord remain free from injury or disease, and therefore competent to perform their functions. Sometimes, however, these fibres participate in the general shock which the spinal cord or brain experiences at the onset of disease or accident, and therefore reflex movements are not to be excited in all cases in which the influence of the brain has been cut off by disease of that organ, or of the cord itself.

This hypothesis has very much to commend it; and not the least argument in its favour is that drawn from the compound nature of spinal nerves, as proved by Bell, in which filaments of very different endowments are bound together in the same sheath. If it be proved that filaments of sensation and of motion may be thus tied together, it is not going too far to conjecture the existence of another series of fibres of distinct function.

The movements of decapitated animals, of parts in connexion with small segments of the spinal cord, of limbs paralysed to sensation and voluntary motion from diseased brain or spinal cord, are satisfactorily explained by this hypothesis. But there are two phenomena familiar to those who observe disease with a knowledge of the many interesting discussions now going on upon the nervous system, which are not explained by it: these are, the movements which may be excited by mental emotion in limbs paralysed to the influence of the will, and the total paralysis of the sphincter ani, which frequently accompanies diseased brain, whilst, at the same time, the limbs are only affected to a partial degree.

Cases occur sometimes in which hemiplegia arises from an apopletic clot or other destructive lesion in one hemisphere of the brain. The arm and leg, or either of them are completely removed from the influence of the will; yet, occasionally, under the influence of some sudden emotion, fear, joy, surprise, the palsied limb is raised involuntarily with considerable force.* Mental emotions probably affect some part of the brain: if the only communication between the brain and the limbs be by the fibres of sensation and volition, it is impossible to understand how, in such a case, the emotional influence could be conveyed through a channel which has long been

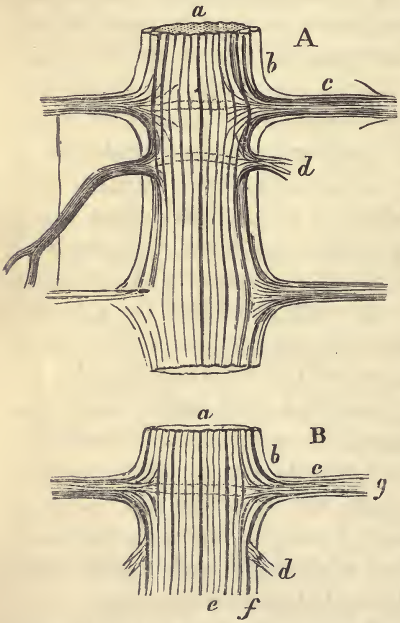
* Even so slight a cause as yawning, which is an action of emotional character, will excite a palsied limb. In the case of a patient now in King's College Hospital with very complete hemiplegia, the arm is raised involuntarily every time he yawns.

stopped. If we are to adopt Dr. Hall's theory, it will be necessary to suppose, with Dr. Carpenter, the existence of certain *emotional* fibres to explain the phenomena of this particular case. But it is difficult to admit the existence of three orders of fibres in each muscle, which, to be effective, must have the same relation to the component elements of the muscle. It is impossible to imagine how each order of fibre should comport itself with reference to the other two, so that their actions may not interfere. Nor can any one fail to perceive that the emotional fibres must be infinitely less frequently employed than the others, and in some individuals, so little called into action, as to expose the fibres greatly to the risk of atrophy for want of use.

Paralysis of the sphincter ani is most frequently produced by disease of the spinal cord; but it is by no means a rare accompaniment of diseased brain, and generally indicates a lesion of grave import. Now, such a lesion is always accompanied with paralysis, chiefly of the hemiplegic kind, but not necessarily complete; on the contrary, in several such cases we have seen distinct reflex movements, indicating, that although the brain's influence was withheld from the limbs, that of the cord was not. If then the cord be sufficiently free from morbid depression to allow of reflex movements taking place in the inferior limbs, why is the sphincter so completely paralysed that it offers not the slightest resistance to the introduction of the finger into the anus? It is admitted that the sphincter is under the influence of the will; according to Dr. Hall's theory, this must be through special fibres of volition distributed to it: but it is also under the influence of the spinal cord, as the limbs are; yet, if the cerebral fibres be diseased, there seems no reason why the influence of the cord upon it should be at the same time destroyed. A cerebral lesion ought not to affect the sphincter further than to destroy the control of the will upon it, unless its depressing influence extend to the whole cord, and in such a case there ought to be complete paralysis of the limbs likewise.

These are not unimportant pathological objections to this theory: to them we must add the fact, that this view wants the support of anatomy. However disposed we may be to admit the existence of fibre implanted solely in the gray matter of the cord, it must be confessed that it is as yet far from being proved that either such fibres, or those which are continued up into the brain, exist in the cord of vertebrata, or in its analogue of the invertebrata. Dr. Carpenter and Mr. Newport, it is true, affirm that they have demonstrated the two sets of fibres in insects—the *sensori-volitional*, and the *excito-motory.* The former author describes the nerves of articulata as consisting of fibres derived from two sources—namely, the anterior or cerebral ganglion, and the ganglion of that segment of the body to which they belong. Those fibres which are connected with the brain, he states, pass down along the dorsal surface of the ganglionic chain, and are fibres of sensation and voluntary motion; those which are immediately implanted in the ganglia are excito-motory. Mr. Newport, in his recent able and elaborate description of the nervous system of Myriapoda, thinks that he shews a somewhat similar arrangement in those animals. The ganglionic chain has on its dorsal surface a pair of columns, *superior longitudinal fibres,* which pass over the ganglia, sending a few fibres to mingle with them, or with an inferior pair of longitudinal columns. These latter, the *inferior longitudinal fibres,* are placed along the abdominal surface of the ganglionic chain, and are intimately connected with the ganglia. In the intervals between the ganglia these two columns lie in close juxtaposition, separated only by some transverse fibres. The inferior columns appear, as Mr. Newport states, to receive fibres from the superior columns, and probably to send some to them, "thus decussating each other in the middle substance of the cord, where these two longitudinal series are in close apposition; since it is almost impossible, even in the large nervous cord of Scolopendra, to separate these two tracts from each other, although their distinctness is evinced in their relative size and longitudinal line of separation."* The ganglia, then, are placed between these two columns the inferior pair being intimately connected with them. Almost the

Fig. 73.



Upper and under surfaces of a portion of the cord in Spirostreptus.—After Newport.
A. Under surface. B. Upper surface.
a. Inferior longitudinal fibres. *e.* Superior longitudinal fibres. *f.* Fibres of reinforcement, also seen at *b* and *c*. *g.* Commissural fibres, also seen at *d*, A.

* Phil. Trans. 1844.

whole of the fibres of the inferior longitudinal series are traceable, says Mr. Newport, in the Iulidæ, directly through each enlargement of the cord which they mainly assist to form. Two other sets of fibres are distinguished by this anatomist in these animals, which do not take a longitudinal course. These are, first, the *commissural* fibres, which pass transversely between corresponding nerves of opposite sides of the body; and secondly, *the fibres of reinforcement of the cord*, which communicate between nerves of the same side of the body, passing from a nerve which arises from a superior ganglion to one that comes from an inferior one. These nerves do not appear to penetrate the cord: judging from Mr. Newport's description, they merely pass from nerve to nerve, forming loops which are convex towards the cord, and constitute the lateral portion of the cord in the intervals between the points of emergence of the nerves with which they are connected. These two sets of *transverse* and *lateral* fibres agree in the fact that they do not pass upwards to the brain; but of their connexion with the cord nothing is known. Indeed it is by no means apparent that the lateral fibres form any junction with the vesicular matter of the cord, or with any other than peripheral portions of the nervous system; Mr. Newport's researches shew only that they are in juxtaposition with the margins of the cord, but we cannot infer from them that they mingle with its elements. Moreover it is far from being proved that the longitudinal fibres pass up to the brain. The brain, indeed, is not necessarily the largest of the ganglia, and it must be admitted to bear a most inadequate proportion to the number of longitudinal fibres. Let any one compare the size of the cerebral ganglia of the scorpion (as figured by Mr. Newport) with the size of the animal and that of its cord, and it will be evident to him how disproportionately small such a centre is to the number of sensori-volitional fibres which must be distributed over so large a surface, and to so many muscles. When, too, it is stated that the observations of these physiologists were made with low powers of the microscope, it must be confessed that there is as much obscurity as to the origin of the nerves in invertebrata as in vertebrata; and that we are not yet entitled to conclude that the existence of two orders of fibres has been actually demonstrated in the former class. Anatomy offers no objection to the hypothesis that the roots of the nerves are implanted in the ganglia, and that the longitudinal fibres act as commissures between different segments (both adjacent and remote) of the cord.

And we may add here, that Mr. Newport's experiments on the myriapods and other articulata throw no light on the question of the existence of two orders of fibres; nor do they add anything to our knowledge beyond the important fact, that actions take place in invertebrata after decapitation which are of the same nature with those which occur in vertebrata after a similar mutilation. The mechanism of these actions has not been at all elucidated by these experiments.

Respecting the second hypothesis, we must remark, that it is just as competent to explain the phenomena of decapitated animals, as paralysed limbs, as that of Dr. Hall, and that it receives some support from the almost universal concurrence of sensation with those normal actions which Dr. Hall would attribute to excito-motory fibres. If it be supposed that these fibres have a certain relation to the gray matter of the spinal cord, there can be no good reason against the further supposition, that they may continue to be affected by it after the brain has been separated from the cord. This hypothesis, however, is liable to the same objections as that of excito-motory fibres: it is inadequate to explain the influence of emotion on paralysed limbs, and the paralysis of the sphincters; and, moreover, it cannot be considered to be proved that fibres are continued up directly from the spinal nerves to the brain. The fibres of the anterior pyramids, no doubt, are true cerebro-spinal fibres; but they may be merely commissural. We have no evidence that fibres of the lumbar region of the cord pass into the brain. The longitudinal course of fibres in the spinal cord affords no proof that those fibres pass into the brain, for it is well known that most of the nerves take a very oblique course from their point of separation from the cord to their emergence from the spinal canal; and it is probable that the fibres continue their obliquity in the cord itself, so that their real origin would be higher up than their apparent one. This great length of oblique course gives to the fibre the appearance of being strictly longitudinal, whereas it may be implanted in the gray matter of the cord.

The third hypothesis appears to us to admit of fewer objections than either of the others, and to be more consonant with what seems to be the correct anatomy of the cord. It supposes that the mechanism of a mental and that of a physical nervous action are essentially the same, differing only in the nature and the mode of application of the stimulus. The same *afferent* and *efferent* fibres are exerted in the one case as in the other; the former acting as *sensitive* or *excitor*, or both; the latter as channels for *voluntary*, *emotional*, or strictly *physical* impulses to emotion.

This hypothesis is content to assume that fibres of sensation and voluntary motion do not pass beyond that particular segment of the cord with which they are connected; and that each segment of the cord communicates readily with the brain through the horns of gray matter, or through commissural fibres which pass between the segments of the cord, and from the upper segment of the latter to the brain. The anatomy of the cord, so far as our present knowledge extends, is favourable to this hypothesis, for it is much more probable that all the roots of the spinal nerves are implanted in their proper segments of the cord, than that some pass up to the brain, and others remain in the cord. The varying dimensions of the cord, at different regions, disincline us to admit the existence of fibres which are continued up into the brain from the spinal nerves. It is impossible to understand the great superiority of size of the lumbar portion over the dorsal segment of the cord, if we admit that this latter segment contains, in addition to its own fibres (sensori-volitional and excito-motory), the sensori-volitional fibres of the lumbar swelling also. The fibres of sensation and volition, which pass to the great lumbar and sacral nerves, could, in that case, be only extremely few in proportion to the excito-motory ones; nor would they seem adequate to the motor and sensitive endowments of the lower extremities; where it must be admitted volition and sensation enjoy an extensive sway. Moreover, it may be stated that the great size of the lumbar swelling depends mainly on the large quantity of vesicular matter which exists in it; and the total amount of fibrous matter is hardly so much as might be expected to exist if the lower extremities and the pelvis were supplied with both sensori-volitional and excito-motory fibres.

It is very generally admitted, that the only channel by which the will can influence the spinal cord is through the fibres of the anterior pyramids, the greater number of which decussate each other along the median line, as already explained in page 265. The most frequent pathological phenomena favour this view. Now it is in the highest degree improbable that these fibres, occupying so small a space as they do, should form the aggregate of the volitional fibres (still less of the sensori-volitional fibres) of the trunk and extremities. It seems to us much more reasonable to regard the fibres of the pyramids in the light of commissures, connecting the gray matter of the cord with that of the brain, and serving to associate these two great divisions of the cerebro-spinal centre in the voluntary, if not in all the mental nervous actions.

The mechanism of a voluntary action, in parts supplied with spinal nerves, would be, according to this hypothesis, as follows:

The impulse of volition, primarily excited in the brain, acts at the same time upon the gray matter of the cord (its anterior horn), which in virtue of its association with the former, by means of the fibres of the anterior pyramids, becomes part and parcel of the organ of the will, and therefore as distinctly amenable to acts of the mind as that portion which is contained within the cranium. If we destroy the commissural connexion through the pyramidal fibres, the spinal cord ceases to take part in mental actions; or, if that connexion be only partially destroyed, that portion of the cord which the injured fibres had associated with the brain is no longer influenced by the mind. Again, if the seat of volition in the brain be diseased, the cord, or part of it, participates in the effects of the disease, as far as regards voluntary actions. That it is not too much to ascribe such power to the pyramidal fibres, appears reasonable, if we consider how the fibres of the corpus callosum, and perhaps other transverse commissures, so connect the hemispheres and other parts of the brain that the separate divisions of a double organ act harmoniously in connexion with the operations of a single mind; or, that, conversely, two impressions from one and the same source on a double sentient organ are perceived as single by the mind.

An objection to this explanation will readily be raised, that the excitation of the anterior horn of the gray matter, in the way stated, does not explain the remarkable power which the will has of *limiting* its action to one or two, or a particular class of muscles. We reply to this, however, that there can be no reason for denying to the mind the faculty of concentrating its action upon a particular series of the elementary parts of the vesicular matter, or even upon one or more vesicles, if we admit that it can direct its influence to one or more individual fibres, as the advocates of the first and second hypothesis do. If, indeed, we admit the one, we must admit the other; for whether the primary excitation of a fibre take place in the encephalon or in the spinal cord, the part first affected must probably be (according to our second postulate) one or more vesicles of the gray substance.

The series of changes which would develop a sensation, admits of the following explanation: A stimulus applied to some part of the trunk or extremities is propagated by the sensitive nerves to the posterior horn of the gray matter of the spinal cord, and from the junction of this part with the brain, either through the direct continuity of the vesicular matter of the cord with that of the centre of sensations, or through longitudinal commissural fibres, analogous to, or even perhaps forming part of, the anterior pyramids, this organ is simultaneous affected. To this likewise it will be objected, that the limitation of sensations is not sufficiently explained. But the reply is obvious: the *intensity* and *kind* of sensation depend upon the nature of the primary stimulus at the surface; the *extent* upon the number of fibres there stimulated. Wherever these fibres form their proper organic connection with the vesicular matter, that matter will participate in their change to an extent proportionate to the number of fibres stimulated, and with an intensity commensurate with the force of the primary stimulus. It is not necessary to the development of sensation that the fibre stimulated should be implanted directly in the brain; if it be connected with this centre through the medium of vesicular matter of the same character as that which is found in it or through commissural fibres, all conditions necessary for the development and propagation of nervous force would appear to be fulfilled. It must not be supposed, however, that in making this statement we mean to assign the spinal cord to be the *seat* of sensation; all we assert is, that the posterior horns of its gray matter, as being the part in which the sensitive roots are implanted, participate largely in the mechanism of sensation; and that by their union with the brain they become, *pro tanto*, a part of the centre of sensation, so long as that union is unimpaired.

This hypothesis offers an explanation of the hitherto unexplained phenomenon of impaired sensation on that side of the body which is opposite to the seat of cerebral lesion. If we regard the anterior pyramids as commissures between the sensitive, as well as between the motor portions of the cerebro-spinal centre, it will be obvious that the posterior horns of the spinal gray matter on the right side will be associated with the left centre of sensation in the brain, and *vice versâ*.

And we gain, moreover, an explanation of the almost universal association of sensation with reflex or physical actions. The excitor nerves of these actions being the same as the sensitive nerves, the impression conveyed by them is calculated at once to excite motion and sensation. Were it not for the controlling influence of the will, all sensitive impressions made through the spinal cord would likewise be accompanied by corresponding movements. When the spinal cord has been excited by strychnine, the physical power prevails over the mental, and the will ceases to be able to control the movements excited by impressions through sensitive nerves.

A highly important argument in favour of this view is derived from the marked difference of structure of the anterior and posterior horns of the spinal vesicular matter. The anterior and posterior roots of the nerves exhibit no difference of structure; no anatomist could distinguish in a compound nerve the sensitive from the motor filaments. The vesicular matter, however, in the anterior horn, contains large caudate vesicles of a remarkable and peculiar kind (fig. 56, p. 214); whilst that in the posterior horn resembles very much the vesicular matter of the cerebral convolutions, and of other parts of the cerebrum, and does not contain caudate vesicles, except near the base. Here, then, we find associated with the well-attested difference in the *functions* of the anterior and posterior roots, a striking difference in the *structure* of the anterior and posterior horns of gray matter.

This hypothesis is adequate to the explanation of the influence of emotion on limbs paralysed as to voluntary movement, without the necessity of assuming the existence of a totally distinct series of fibres for this class of actions. The change in the brain, excited by emotion, is propagated to the spinal gray matter, in a manner analogous to that in which the influence of the will is brought to bear on it. It thus affects the ordinary motor fibres; and, therefore, the movements which are produced by emotion resemble very closely those excited by the will.

This hypothesis suggests a very obvious explanation of the kind of antagonism which appears to exist between voluntary and reflex actions. It is well known that in health the will can in a great degree control and prevent the development of reflex actions in the lower extremities. If one be paralysed, as in hemiplegia, from disease of the brain, whilst the other remains sound, a very striking contrast is sometimes to be observed between the two limbs. On stimulating the sole of the foot in the diseased limb, reflex actions are readily produced; but, on applying the same stimulus to the same part of the sound limb, no such movements occur, the patient being conscious of the application of the stimulus, but resisting the tendency to action which it produces. The will has lost its control over the diseased limb; but, as the motor nerves and the spinal gray matter are sound, actions may be still excited through a stimulus from the periphery; and, the more complete has been the separation of the brain's influence from the cord, the more perfect will be the reflex actions. Hence we frequently find these movements more perfect in cases where sensation as well as voluntary power is destroyed in a limb, than where the latter only has ceased.

It may be here remarked, that movements which at one time are voluntary, may at another time be physical. If the influence of the will be suspended for a brief period, stimulation of the surface will produce the same movements which previously were excited by voluntary impulse. Thus, tickling the soles of the feet, in a person asleep, excites movements which doubtless are of the reflex kind; but the same stimulation, in a person awake, will give rise to precisely the same movements, which he is conscious are, at least in a great degree, voluntary.

Some reflex actions are imperfectly controllable by the will; of which the contraction of the pupil, and the movement of deglutition at the isthmus faucium, are examples. It is remarkable, however, that the will may give rise to these actions by associating others with them: the pupil may be contracted at will, by directing the eye inwards; and the fauces may be contracted by bringing some saliva in contact with them. In the latter case, the stimulus of volition alone is not sufficient to excite the movement; the addition of a physical stimulus is likewise necessary: and, in the former, the excitability of the fibres of the third nerve by a mental stimulus may be materially modified by their re-association with vesicular matter in the ophthalmic ganglion.

There is nothing in this hypothesis repugnant to the idea, that certain nerves may be connected in the centres with masses of vesicular matter over which the will usually exercises little or no control, and which perhaps, have but a slight connexion with the brain through commissural fibres. Facts like those instanced in the preceding paragraphs may be accounted for on such a supposition as this. This supposition may be required to explain some of the actions of nerves connected with the medulla oblongata, the vagus for instance, but certainly not of spinal nerves.

It is probable that in many actions the double stimulus, mental and physical, is necessary to their perfect development. The former is excited by the mind acting on the vesicular matter; the latter is propagated at the same time, by sensitive nerves, to the same region of vesicular matter; and both simultaneously influence the same motor fibres. In locomotion, it seems probable that this is the case: the degree of contraction of the muscles necessary to maintain the superincumbent weight is obtained by the physical stimulus of pressure against the soles of the feet; but the movements of the limbs, and the harmonizing association of the muscular actions, is effected by mental influence. The pressure against the soles is felt, however; and the same nerve-fibres which excite the sensation, stimulate the vesicular matter in which the motor nerves are implanted. In many actions of familiar occurrence, the voluntary effort is greatly enhanced by the simultaneous application of a physical stimulus to a part of the surface which is supplied with nerves from the same region of the cord. The horseman feels more secure when his legs are in close contact with the horse's flank. We gain a much firmer hold of an object which adapts itself well to the palmar surface of the hand, than of one which, although of no greater bulk, is yet so irregular in surface as not to allow of such intimate contact with the palm. Closure of the eyelids in winking is an action of similar kind, resulting from a physical stimulus, which in the perfect state of the cerebro-spinal centre produces sensation, and excites motion which is at once the result of the physical impression, and of the exercise of volition provoked by the sensation. Every one must be conscious that he exercises considerable control over the movements of his eyelids, and that it requires a great effort to prevent winking for a certain period. At length, however, the physical impression, arising from the contact of air with the conjunctiva, and the diminution of temperature from evaporation on the surface of that membrane, which at first caused but a slight sensation, produces *pain*; the physical stimulus overcomes the mental resistance, and causes contraction of the orbicular muscle. And it may be remarked further, that the closure of the lids by voluntary effort is much more powerful if a stimulus be applied at the same time to the conjunctival surface, than if left solely to the exercise of the will.

In the action just referred to, as well as in all other instances of reflex actions which the will can prevent, no satisfactory explanation of this controlling power of the mind can be given by Dr. Hall's hypothesis—Do the volitional fibres exceed in number the excito-motory? If this were admitted, then we could understand that an excito-motory act might be prevented by substituting a voluntary act for it; but, in the cases in question, the mind prevents action altogether, notwithstanding the exciting influence of the impression. The true explanation seems to be, that the mind can exert upon the vesicular matter a power which can prevent the exercise of that change, or neutralise the change, without which the motor fibres will not be affected by a physical stimulus.

Reflex actions are more manifest in some situations than others: thus, in cases of hemiplegia from diseased brain, they are generally very obvious in the lower extremity, but totally absent in the upper. This, the advocates of the excito-motary theory ascribe to a paucity of excito-motory fibres in the latter limb, and to a larger amount of them in the former. Or, it has been attributed to the greater and more enduring influence of shock upon that segment of the cord from which the nerves of the upper extremities arise, as nearer the seat of lesion, than upon the lumbar segment. But another explanation appears to us equally satisfactory, and more accordant with other phenomena. A certain *disposition of the nerves upon the tegumentary surface is as necessary for the development of reflex actions as of sensations;* and these movements will be more or less easily manifested, according as this organization of the nerves on the surface is more or less perfect.

That disposition of the cutaneous nerves which renders the surface easily excitable by titillation seems most favourable to the development of these actions. Hence, there is no place where they are more readily excited than in the lower extremities by stimulating the soles of the feet or the intervals between the toes, both of which situations are highly susceptible of titillation. At the isthmus faucium the slightest touch on the surface excites a movement of deglutition; and this touch, at the same time, produces a very peculiar sensation of tickling, quite distinct from that which may be excited at other parts of the pharynx, or mouth. When this part of the mucous membrane is in a state of irritation as an effect of coryza, this tickling sensation is present, and repeated acts of swallowing are provoked.

Two facts may be stated here, which illustrate the position we have laid down respecting the necessity of a certain disposition of the nerves *on the tegumental surface*, for the development of reflex actions. The first is one which has been noticed by Volkmann, and which we had ourselves repeatedly observed, namely, that in frogs, and other animals, reflex actions are readily excited by stimulating the feet; but irritating the posterior roots of the spinal nerves, which supply those parts, is not sufficient for this purpose. In experiments repeatedly made upon the posterior roots of the nerves we have very rarely seen movements excited whilst they have been subjected to irritation, and the recorded statements of all modern experimenters agree in the main with this statement. The second fact is this: in the male frog the development of a papillary structure on the skin of the thumb seems to have reference to the excitation of the physical power of the cord, to enable the animal to grasp the female without the necessity of a prolonged exercise of volition. Stimulating the fingers will scarcely produce reflex actions, but the slightest touch to the enlarged thumb will cause the animal to assume the attitude of grasping. If the papillæ be shaved off the thumb, its power of exciting these actions is instantly lost.

When the polarity of the cord is greatly excited by strychnine or other substances, or when tetanus exists, all parts of the surface are equally capable of exciting reflex actions. The least touch will cause them, not only in the limb touched, but in all that side of the trunk, or even throughout the whole body. So general is the excitation, that the least impression made on the peripheral extremity of a sensitive nerve in any part of the body is instantly converted into muscular spasm, more or less general. A slight current of air, in tetanus, is sufficient to excite general spasm. Müller remarks, that, in such states of the cord, the reflex actions excited by stimulating the nerves themselves are much less than those produced by excitation of the surface.

The readiness with which a physical change, induced in one part of the centre, is propagated to others, whether above or below it, is due no doubt to the vesicular matter. An experiment made by Van Deen illustrates this statement. If, in an animal poisoned by strychnine, the cord be divided in its entire length along the median line, leaving only a slight bridge of gray matter, stimuli applied to any part of the surface will exhibit as extensive reactions as if the cord were entire. It is evident that the only medium of communication between the opposite halves, must be the small portion of vesicular matter left undivided.

Impressions conveyed to the cord by the posterior roots of any of its nerves, may be reflected to the corresponding motor nerves, and cause movement, or may extend irregularly along the posterior horns of gray matter and stimulate the nerves implanted in them, and thus give rise to new sensations, which may be referred to other and even distant parts of the body.

The hypothesis, under consideration, affords us an explanation, more satisfactory than any other, of the paralytic state of the sphincter ani in brain disease, already referred to, as well as in that of the spinal cord. This muscle is certainly chiefly under the influence of the will. In ordinary cases of diseased brain where the lesion is confined to one side, the centre of volition is not sufficiently impaired to affect its influence upon the sphincter. In graver lesions, however, although the will may still continue to exert its control upon one side of the body, it loses its power over the sphincter, which is not excitable by any stimulus. In disease of the spinal cord, there is paralysis of the sphincters if the lesion involve a sufficient portion of the cord's substance, in whatever region of the cord it may exist. Even when the lesion is situate high up in the neck, or in the dorsal region, leaving the lumbar portion perfectly whole, the sphincter will nevertheless be paralysed. In the former instances, the centre of volition in the cranium is diseased; in the latter, the defect consists in the destruction of the communication of the brain with that portion of the cord in which the nerves of the sphincter muscle are implanted.

An examination of the action of the sphincter will shew that the anus is kept closed ordinarily by the passive contraction of the muscle itself (see p. 191); but that its active contractions are mainly excited by voluntary influence, allowance being made for some slight action which may be produced by the stimulus of sudden distention, as in other circular muscles. Now, as a stimulus to sentient nerves constitutes no necessary part of any of these actions, it is probable that the motor nerves of the sphincter have little or no connexion with the sentient ones: and, consequently, that muscle is not excitable to contraction by a stimulus applied to a sentient surface. Hence, whenever the influence of the will upon the lumbar portion of the cord is suspended, this muscle ceases to act, whether a mental or a physical stimulus be exerted.

Dr. Hall, indeed, cites two experiments which imply that the action of the sphincter is dependent on the cord. In both, however (one on a horse, the other on a turtle), the observations were made immediately after division of the cord. By the division, the whole organ was thrown into an excited state, both above and below the section, and therefore manifested phenomena similar to those excited by volition. Indeed, we have seen the sphincter repeatedly contracting after division of the cord without the application of any new stimulus to it; and the dog continuing to raise and depress his tail as long as the irritation of the cord produced by the section has continued.

On the same principle, animals will exhibit movements of voluntary character for some time after decapitation. A bird thus treated will fly for some distance, and with considerable energy, and will flap its wings if the cut surface of the cord be irritated. A fly decapitated flies for some way immediately after the removal of the head; and Walckenaer observed a singular fact respecting the Cerceris ornata, a wasp which attacks a bee that inhabits holes: "at the moment that the insect was forcing its way into the hole of the bee, Walckenaer decapitated it; notwithstanding which, it continued its motions, and, when turned round, endeavoured to resume its position, and enter the hole."* The change in the

* Quoted in Müller's Physiology; by Baly, vol. i. p. 787*, 2nd ed.

vesicular matter of the ganglia necessary for the movements of the wasp in pursuit of its prey, had already been excited by a powerful stimulus of volition, which continued even after the removal of the centre from which it had emanated.

So similar is the change which a physical stimulus can excite in the gray matter to that produced by the influence of the will, that, as has been often remarked, the actions excited in decapitated animals present a striking resemblance to the ordinary voluntary movements. When a certain portion of the skin is irritated, the animal pushes against the offending substance, as if trying to remove or displace it. If the anus be irritated, both legs are excited to action. It may also be observed, that the same motions follow the same irritations of the skin. If, in a frog, the seat of irritation be on the right side, the corresponding hind-foot will be raised, as if to remove the irritating cause. The exact resemblance of these to voluntary movements seems to admit of being explained only on the supposition that the same fibres are employed in the execution of both.

It must be borne in mind, that, while this hypothesis rejects the class of sensori-volitional fibres which pass with the spinal nerves along the cord into the brain, it admits the existence of only three orders of fibres implanted in the various segments of the cord, viz. those at once sensitive and excitor; those at once for voluntary and involuntary motion; and commissural fibres. Moreover, it is not intended by this hypothesis to assume that the intervention of *sensation* (*i.e.* the perception of an impression by the mind) is *necessary* for the production of those muscular actions which are excited by stimulation of the surface. No more is affirmed than that the same stimulus to the sensitive nerve which can and does excite a sensation, may *simultaneously*, but *independently*, cause a change in the vesicular matter which shall stimulate the motor nerves; and that this change is of the same kind as that which the will may excite, and affects the same motor nerves.

Lastly, this hypothesis involves the enunciation of a highly important proposition with reference to nervous centres. It is this: that all the centres which are connected to the brain by commissural fibres, are thereby submitted to, and brought into connexion with, the mind, to an extent proportionate to the number of connecting fibres, so that voluntary impulses act upon them as part and parcel of the centre of volition; and sensitive impressions, in affecting them, affect the sensorium commune simultaneously.

In voluntary actions, then, it may be stated, that while the brain is the part primarily affected, the mental impulse is at the same time directed to that portion of the cord upon which the required action depends.

In the development of sensation the stimulus affects the posterior horns of the gray matter of the cord, which, from its commissural connexion with the brain, is in reality a part of the sensorium. When the power of mental interference is removed, or kept under control, physical actions develop themselves; being affected through the same nerves as those which volition influences, or which sensitive impressions affect. The latter are, in such instances, the excitors of the former, no doubt through the vesicular matter in which they are implanted. These actions become most manifest when the connexion of the brain with the spinal cord has been severed; and they occur in the most marked way in those situations where the cutaneous nerves are so organized as readily to respond to the application of a stimulus applied to the surface, or they become universal when the cord is in a state of general excitement.

The movements in locomotion and the maintenance of the various attitudes, are affected through the ordinary channels of the physical and volitional actions; and the posterior columns of the cord, by their influence on the vesicular matter of the segments in which the nerves are implanted, co-ordinate and harmonize the complicated muscular actions of the limbs and the trunk under the control of that portion of the encephalon which probably is devoted to that purpose. This power of co-ordination is probably mental, and intimately connected with the muscular sense.

To conclude the discussion of the functions of the cord, we shall here enumerate the physical nervous actions of which it is the centre, remarking, at the same time, that we continue to use the term spinal cord in its ordinary sense, and that we reject the hypothesis of a *true spinal cord,* anatomically distinct from that which has to do with mental nervous actions.

We have already stated, that probably part of the muscular adjustments in locomotion are excited by the pressure against the soles of the feet. All involuntary movements of the muscles of the trunk or extremities, when excited by external stimuli, have their centre in the spinal cord. The sudden application of cold to the surface of the trunk or extremities, frequently excites respiratory movements. This may be attributed to cutaneous nerves affecting the gray matter of the cord, and through this the intercostal and phrenic nerves implanted in it.

Certain conditions of the generative organs are dependent on the spinal cord; but they are developed only in a polar state of that organ, usually present under sexual excitement. Erection of the penis is evidently dependent on the cord in this way. In a state of irritation of the cord, such as may be caused by traumatic injury, erection or semi-erection is frequently present. In paraplegia there is frequently an absence of the power. The excited state of the Fallopian tubes in the female is attributable to the same cause. The action of the uterus in parturition, and that of the bladder and rectum when distended, is partly due to the stimulus of distension on the muscular coats, and partly to the physical power of the cord excited by the sensitive nerves of those organs.

The nervous actions which accompany the nutritive functions are of the physical kind, although not altogether removed from the influence of volition and emotion, and have their centre in the spinal cord. Thus, the heart is very liable to be influenced by the spinal cord, and, no doubt, the blood-vessels are similarly related to it; and, through their influence upon the distribution of blood to the various textures, it is plain that the state of the spinal cord, or of parts of it, may readily affect the molecular changes in which nutrition and secretion intrinsically consist. This subject will be further discussed when we come to consider the functions in question.

It has been supposed, that the tone of the muscular system is maintained by the spinal cord. If by *tone* be meant what we have described as *passive contraction*, we can only remark, that the phenomena which characterize that state are just as obvious in muscles taken from animals recently deprived of the spinal cord as in others; and that the analogous state, rigor mortis, comes on as distinctly when the spinal cord and brain have been removed, as if they were untouched. Healthy nutrition, in our opinion, supplies all the conditions necessary for the maintenance of the tone or the passive contraction; nor is the spinal cord (although itself healthy) able to preserve the tense condition of the muscles, if they are not well nourished. The removal of the spinal cord, indeed, immediately produces a flaccid state of the muscles of the limbs; but this is owing to the immediate cessation of the slight degree of active contraction necessary to maintain a certain posture. A decapitated frog will continue in the sitting posture through the influence of the spinal cord; but immediately this organ is removed, the limbs fall apart, from the loss of the controlling and co-ordinating influence of the nervous centres. But careful examination will show, that in these limbs the molecular phenomena which characterize passive contraction continue. It must be remarked, however, that muscles separated from their proper nervous connexion soon suffer in their nutrition, from the want of that amount of exercise which is necessary for it. For this important observation we are indebted to Professor John Reid, who likewise called attention to the confirmatory fact, that, in those palsies with which there is combined more or less irritation of the nervous centre, the muscles do not suffer in their nutrition, in consequence of the exercise they undergo in the startings so frequently excited in them by the central irritation.

After these remarks, it is scarcely necessary to add, that we must enter our protest against the doctrine which assigns the spinal cord as the source of muscular irritability. This doctrine, indeed, has but slender support either in reason or experience. It is contrary to all analogy to assign to one tissue the power of conferring vital properties on another. If bone, tendon, and cartilage have their distinctive properties, they possess them in virtue of some peculiarity inherent in their mode of nutrition, and do not derive them from any other texture. And, surely, it is too much to suppose that a tissue, like muscle, so complex in its chemical constitution, and so exquisitely organized for the development of its proper force, should be dependent on the nervous system, or a portion of it, for its contractile power! Our own experience is quite opposed to the statement of Dr. Hall, that in cases of palsy dependent on cerebral lesion, the muscles of the affected limbs acquire an increased irritability, from the cord, which he supposes to be the source of irritability, remaining intact, while the influence of the exhauster of irritability (the brain) is removed. In all our experiments, which have been numerous, we have found the palsied muscles less excitable by the galvanic stimulus than those of the sound side, and the difference has been more manifest the longer the period since the paralytic seizure. Exceptions to this statement, however, are found in those cases in which the paralysis has been accompanied with cerebral irritation sufficient to keep up a state of more or less *active* contraction of the affected muscles.*

Functions of the Medulla Oblongata, Mesocephale, Corpora Striata, and Optic Thalami.—Although the anatomist may find it convenient to describe these parts each by itself, it is impossible, in the consideration of their functions, to separate them completely, they are so closely connected with each other, and the functions of

* See also Dr. Pereira's experiments, Mat. Med. vol. ii. p. 1301.

one part are so readily affected by any change in those of the other. Thus, the olivary columns, which form the central and most essential part of the medulla oblongata, extend upwards through the mesocephale to the optic thalami; and the anterior pyramids form an intimate connexion not only with the vesicular matter of the mesocephale, but, to a great extent, with that of the corpora striata. All these parts taken together, with the quadrigeminal tubercles, will be found to be the centre of the principal mental nervous actions, and of certain physical actions which are very essential to the integrity of the œconomy.

The office of the nerves which arise from this segment of the encephalon throws light upon its function. These nerves are partly destined for respiration, partly for deglutition, and partly also for acts of volition and sensation.

Destruction of the medulla oblongata is followed by the immediate cessation of the phenomena of respiration; and this takes place whether it be simply divided, or completely removed. When an animal is pithed, he falls down apparently senseless, and exhibiting only such convulsive movements as may be due to the irritation of the medulla by the section, or such reflex actions as may be excited by the application of a stimulus to some part of the trunk.

If, in an animal which breathes without a diaphragm, as in a bird or reptile, the spinal cord be gradually removed in successive portions, proceeding from below, up to within a short distance of the medulla oblongata, loss of motor and sensitive power takes place successively in the segments of the body with which the removed portions of the cord were connected. But the animal still retains its power of perceiving impressions made on those parts of the body which preserve their nervous connexion with the medulla oblongata, and continues to exercise voluntary control over the movements of those parts. The movements of respiration go on, and deglutition is performed. The higher senses are unimpaired.*

These phenomena are sometimes observed in man — in such cases as that alluded to in a former page; where from injury to the spinal cord in the neck, below the origin of the phrenic nerve, the patient appears as a living head with a dead trunk. The sensibility and motor power of the head are perfect; respiration goes on partially, and deglutition can be readily performed. The senses and the intellectual faculties remain for a time unimpaired.

Irritation of any part of the medulla oblongata excites con-

* Flourens, p. 179.

vulsive movements in muscular parts which receive nerves from it, and, through the spinal cord, in the muscles of the trunk. Spasm of the glottis, difficulty of deglutitition, irregular acts of breathing, result from irritation of the medulla oblongata: and, if the excitement be propagated to the cord, convulsions will become more or less general.

If a lesion affect one half of the medulla oblongata, does it produce convulsions or paralysis on the opposite side of the body? This question may certainly be answered in the affirmative, when the seat of the lesion is in the continuations of the columns of the medulla oblongata above the posterior margin of the pons. It is not so easily solved, however, when the disease is situate below the pons. The results of experiment on this subject are contradictory, owing probably to the extreme difficulty of limiting the injury inflicted to a portion of the medulla on one side; and those of Flourens are of no value for the decision of this question, as it appears that he injured chiefly the restiform bodies. Anatomy suggests, that a lesion limited to either anterior pyramid would affect the *opposite* side of the trunk; for it is known that such an effect follows disease of the continuation of it in the mesocephale or crus cerebri; and that lesion limited to the posterior half of the medulla on either side would affect the *same* side of the body, no decussation existing between the fibres of opposite restiform or posterior pyramidal bodies. The irritating or depressing influence of the lesion would probably be extended to the spinal gray matter of the same side.

That the medulla oblongata is the channel through which the operations of the brain are associated in voluntary actions with the spinal cord, is shown by the fact that paralysis of all the muscles of the trunk follows the separation of the latter organ from the former. It seems not improbable, that the centre of volition is connected with one or both of the glangliform bodies (corpora striata and optic thalami) in which the columns of the medulla oblongata terminate above. When the cerebral hemispheres have been removed, as in Flourens' and in Majendie's experiments, the bird is thrown into a deep sleep, a state of stupefaction, and insensibility to surrounding objects. But he can maintain his attitude—stand—walk, when first propelled—fly, if thrown into the air. This continuance of the locomotive power implies some degree at least of mental or volitional effort. All the animal's movements have much of the appearance of the exercise of will, although, doubtless, many of them are in a great degree excited by physical stimuli. Hence there seems reason to believe that the will exerts a primary influence upon either or both of these gangliform bodies, more vigorous when aided and guided by the power of the cerebral hemispheres. The frequent paralysis of motion apart from sensation, when the upward continuations of the pyramidal fibres in the corpora striata are diseased, renders it extremely probable that these fibres are the media of connexion between the brain and cord in voluntary actions.

The medulla oblongata is not less the medium for the transmission of sensitive impressions from all the regions of the head, trunk, and extremities; and from its olivary columns at their upper and posterior part being, as it were, the concourse of all the nerves of pure sense, it seems fair to assign these parts as the prime seat of those central impressions which are necessary for sensation. The reception of these impressions by the cerebral hemispheres is the stage immediately associated with mental perception. True sensation, therefore, cannot take place without cerebral hemispheres. In a sensation excited in parts supplied by spinal nerves, the first central change is probably in the posterior horn of the vesicular matter of the cord; and the olivary column of the medulla oblongata is simultaneously affected, from its connexion with the cord. The change in this latter part is then propagated to the cerebral hemispheres.

Thus much is suggested by anatomy, as regards the mechanism of sensitive impressions. Experiment affords us no aid in this intricate and difficult subject; neither does pathological anatomy: for the parts are so closely associated with each other, that any morbid state of one readily involves the others, so that it is almost impossible to find a morbid state of the parts devoted to sensation, apart from an affection of those more immediately concerned in motion.

The function of the restiform bodies is probably associated with that of the hemispheres of the cerebellum, and of the posterior columns of the spinal cord.

The experiments of Le Gallois and Flourens render it certain that the medulla oblongata is the centre of respiratory movements. The latter physiologist assigns as the "primum movens" of these acts all that portion of the medulla which extends from the filaments of origin of the vagus nerve to the tubercula quadrigemina, the former only inclusive. Destruction of this portion, in whole or in part, invariably impairs or destroys the respiratory actions, and a morbid state of it gives rise to irregular or excited movements of respiration. Sighing, yawning, coughing, are probably connected with excitation of this centre, either direct, or propagated to it from some sentient surface.

This portion of the encephalon is also the centre of action in the movements of deglutition, through fibres of the glosso-pharyngeal and vagi nerves. A morbid state of it occasions difficulty, or even paralysis, of deglutition. Animals deprived of the cerebral hemispheres and cerebellum will preserve the power of swallowing food introduced within the grasp of the fauces, so long as the medulla oblongata continues uninjured. In fœtuses born without cerebral hemispheres, those actions are present which depend on the spinal cord and medulla oblongata; all the movements of respiration and deglutition are performed as well as in the perfect fœtus. Mr. Grainger's experiments shew that puppies deprived of the hemispheres of the brain can perform the movements of suction with considerable vigour, when the finger is introduced into the mouth;* and the remarkable fact of the adhesion of the fœtus of the kangaroo to the nipple within the pouch, no less than its respiratory movements, must, as this author remarks, be regarded as a most interesting display of the physical power of the medulla oblongata, while the rest of the brain is as yet undeveloped.

The actions of respiration and deglutition are, to a great extent, of the physical kind, being excited by impressions propagated from the periphery. In those of respiration, the ordinary exciting cause is probably, as Dr. Hall supposes, due to the chemical changes in the respired air which are effected in the lungs. These movements may be, to a certain extent, controlled by the will; but every one is conscious, from his own sensations, that after a time the physical stimulus is capable of conquering the restraining influence of the mind; a striking example of a mental stimulus giving way to a physical one; and illustrative, as we think, of the doctrine that the same fibres are affected by both stimuli. The excitation of the medulla oblongata in respiration does not, however, depend solely upon the pulmonary nerves. Those of the skin are capable of exciting it, either directly as the fifth pair, or through the spinal cord, as it is proved by the inspirations which are instantly excited by suddenly dashing water on the face or trunk.

In deglutition, the exciting cause is the stimulus of contact applied to the mucous membrane of the fauces. So highly sensitive is the mucous membrane in this situation, that the slightest touch of it with a feather is sufficient to produce contraction of the

* Loc. cit. pp. 80, 81.

muscles of deglutition, which the will is scarcely able to control. Without this stimulus, it is doubtful whether these muscles would obey the will alone; and it seems probable that this part of the act of deglutition must be regarded as one of those actions referred to at a former page, which require a double stimulus, both mental and physical, for their full performance. (See p. 333).

The medulla oblongata and its continuations in the mesocephale appear to be the centre of those actions which are influenced by emotion. The common excitement of movements of deglutition or respiration, or of sensations referred to the throat, under the influence of emotion, evidently points to this part of the cerebro-spinal centre as being very prone to obey such impulses; and as the nerves of pure sense, especially the optic and auditory, are very commonly the channels of sensitive impressions well calculated to arouse the feelings, it seems highly probable that the centre of such actions should be contiguous to the origin of these nerves. We would assign this office to that region of the mesocephale which is in the vicinity of the quadrigeminal tubercles. It is not a little remarkable that the nerves which arise from this and the neighbouring parts are very readily influenced by emotions. Thus, the third and fourth pairs of nerves regulate the principal movements of the eyeballs, those especially which most quickly betray emotional excitement; and the portia dura of the seventh pair, the motor nerve of the face is the medium through which changes of the countenance are effected. It may be added, that the centre of emotional actions ought to be so situated that it could readily communicate with the centres of all the voluntary actions of the body, and with the immediate seat of the intellectual operations, as well as with the nerves of pure sense; and no part possesses these relations so completely as that to which we refer.

In those diseases which mental emotion is apt to give rise to, many of the symptoms are referrible to affection of the medulla oblongata. In hysteria, the globus, or peculiar sense of suffocation or constriction about the fauces; in chorea, the difficulty of deglutition, the peculiar movement of the tongue, the excited state of the countenance, the difficulty of articulation, may be attributed to the exalted polarity of the centre of emotional actions. In hydrophobia this part is probably always affected, and frequently so in tetanus.

Certain gangliform bodies are connected with the upper continuations of the medulla oblongata, both in the brain and in the mesocephale, which doubtless have proper functions. These are the corpora striata, optic thalami, and quadrigeminal bodies.

Corpora Striata.—The anatomy of the corpora striata and optic thalami, while it denotes a very intimate union between them, also shews so manifest a difference in their structural characters, that it cannot be doubted that they perform essentially different functions. In the corpora striata the fibrous matter is arranged in distinct fascicles of very different size, many, if not all of which, form a special connexion with its vesicular matter. In the optic thalami, on the other hand, the fibrous matter forms a very intricate interlacement, which is equally complicated at every part. Innumerable fibres pass from one to the other, and both are connected to the hemispheres by extensive radiations of fibrous matter. The corpora striata, however, are connected chiefly, if not solely, with the inferior fibrous layer of each crus cerebri; whilst the optic thalami are continuous with the superior part of each crus, which is situate above the locus niger.

It will be observed, then, that while these bodies possess, as a principal character in common, their extensive connexion with the cerebral hemispheres, or, in other words, with the convoluted surface of the brain, they are, in the most marked way, connected inferiorly with separate and distinct portions of the medulla oblongata; the corpora striata with the inferior fibrous planes of the crura cerebri and their continuations, the anterior pyramids; and the optic thalami with the olivary columns, the central and probably fundamental portions of the medulla oblongata. And this anatomical fact must be taken as an additional proof of their possessing separate functions.

Now, it may be inferred, from their connexions with nerves chiefly of a sensitive kind, that the olivary columns, and the optic thalami, which are continuous with them, are chiefly concerned in the reception of sensitive impressions, which may principally have reference merely to informing the mind (so to speak), or partly to the excitation of motion, as in deglutition, respiration, etc. The posterior horns of the gray matter of the cord, either by their direct continuity with the olivary columns, or their union with them through commissural fibres, become part and parcel of a great centre of sensation, whether for mental or physical actions.

The pyramidal bodies evidently connect the gray matter of the cord (its anterior horns?) with the corpora striata; and not only these, but also the intervening masses of vesicular matter, such as the locus niger, and the vesicular matter of the pons, and of the olivary columns; and, supposing the corpora striata to be centres of volition in intimate connexion with the convoluted surface of the brain in their numerous radiations, all these several parts are linked together for the common purposes of volition, and constitute a great centre of voluntary actions, amenable to the influence of the will at every point.

It has been pretty generally admitted by anatomists, that both the corpora striata and the anterior pyramids are concerned in voluntary movements. The motor tracts of Bell were regarded by that physiologist as passing upwards from the anterior columns of the cord to the corpora striata, and, after traversing those bodies, as diverging into the fibrous matter of the hemispheres; and the fact of the origin of certain motor nerves, in connexion with those fibres, was considered to be very favourable to this view. The decussation of the pyramids, likewise, so illustrative of the cross influence of the brain in lesions sufficient to produce paralysis, has been looked upon as an additional indication of the motor influence of these parts.

The invariable occurrence of paralysis as the result of lesion, even of slight amount, in the corpora striata, must be regarded as a fact of strong import in reference to the motor functions of these bodies.

Nor is this fact at all incompatible with the statements made by all experimenters, that simple section of the corpus striatum does not occasion either marked paralysis or convulsion; and that in cutting away the different segments of the brain, beginning with the hemispheres, convulsions are not excited until the region of the mesocephale are involved. The influence of the corpora striata is not upon the nerves *directly*, but upon the segments of the medulla oblongata or of the spinal cord, and, through them, upon the nerves which arise from them. Were the nerve-fibres continued up into the corpora striata, according to an opinion which has been long prevalent, there would be no good reason for supposing that they should lose in the brain that excitability to physical stimuli which they are known to possess in the spinal cord, and at their peripheral distribution.

The latest experiments, which are those of Longet and Lafargue, agree in the following result, which is not at variance with that obtained by Flourens. The animals remain immoveable after the removal of the corpora striata, whether those bodies have been removed alone or in conjunction with the hemispheres; nor do they shew any disposition to move, unless strongly excited by some external stimulus. None of these observers had noticed the irresistible tendency to rapid propulsion, which was described by

Majendie. Removal of the corpus striatum of one side caused weakness of the opposite side.

In order to form a due estimate of these experiments, it must be borne in mind, that the effects of simple excision of either corpus striatum would be very different from those of disease of it. The depressing effects of the latter would be absent, at least, until some alteration in the process of nutrition had been set up in the mutilated parts. Simple excision of the centre of volition, and inflammatory disease of its substance, or an apopletic clot, must produce essentially different effects; — the one simply cuts off the influence of the will, the other affects the vital action, and, consequently, the vital power of the centre, and of the commissural fibres connected with it.

Judging from structure only, it might be conjectured that the *locus niger*, that remarkable mass of vesicular matter which separates the anterior and posterior planes of each crus cerebri, exerts a motor influence. It resembles in structure the anterior horns of the gray matter of the cord, and contains numerous large caudate vesicles with very abundant pigment.

Optic Thalami.—The same line of argument which leads us to view the corpora striata as the more essential parts of the nervous apparatus which control direct voluntary movements, suggests that the optic thalami may be viewed as the principal foci of sensibility, without which the mind could not perceive the physical change resulting from a sensitive impression.

The principal anatomical fact which favours this conclusion, is the connexion of all the nerves of pure sense, more or less directly, with the optic thalami or with the olivary columns. The olfactory processes, which apparently have no connexion with them, form, no doubt, through the fornix, such an union with them, as readily to bring them within the influence of the olfactory nerves.

According to this sense of its office, we must regard the optic thalami as the upper and chief portions of an extended centre, of which the lower part is formed by the olivary columns, which we have already referred to as taking part in the mechanism of sensation. The continuity of the olivary columns with the optic thalami justifies this view: nor is it invalidated by the fact, that some of the nerves which arise from the medulla oblongata are motor in function; for Stilling's researches render it probable that these fibres have their origin in special accumulations of vesicular matter, which contain caudate vesicles of the same kind as those found in the anterior horns of the gray matter of the cord. (See fig 70).

The results which experiments have yielded, add little that is positive to our knowledge of the functions of these bodies. Flourens found that neither pricking nor cutting away the optic thalami by successive slices, occasioned any muscular agitation, nor did it even induce contraction of the pupils. Longet found that removal of one optic thalamus in the rabbit was followed by paralysis on the opposite side of the body. It appears, however, that this was done after the removal of the hemisphere and corpus striatum, whereby the experiment was so complicated as to invalidate any conclusion that might be drawn from it respecting the function of the thalamus. Indeed, vivisections upon so complex an organ as the brain are ill-calculated to lead to useful or satisfactory results; but we do not hesitate to quote such as have been made, from the imperfect negative information which they afford.

Nothing definitive respecting the proper office of the thalami can be obtained from pathological anatomy. Extensive disease of these bodies is attended with the same phenomena during life, as lesion of similar kind in the corpora striata. Hemiplegic paralysis accompanies both; nor does it appear, that sensation is impaired when the thalamus is diseased, more than when the corpus striatum is affected.

We see nothing in the phenomena which attend morbid states of the thalami, to oppose the conclusion which their anatomical relations indicate, namely, that they form a principal part of the centre of sensation. The intimate connexion between the striated bodies and the thalami, sufficiently explain the paralysis of motion which follows disease of the latter; whilst, as the thalami do not constitute the *whole centre* of sensation, but only a part, it cannot be expected that lesion of this part would destroy sensation, so long as the remainder of the centre on the same side, as well as that of the opposite side, retain their integrity. Complete paralysis of sensation on one side is very rare in diseased brain: a slight impairment of it frequently exists in the early periods of cerebral lesion, apparently as an effect of shock; for it quickly subsides, although the motor power may never return.

According to the views above expressed, the corpora striata and optic thalami bear to each other a relation analogous to that of the anterior to the posterior horn of the spinal gray matter. The corpora striata and anterior horns are centres of motion; the optic thalami and posterior horns, centres of sensation. The anterior pyramids connect the former; the olivary columns, and perhaps some fibres of the anterior pyramids, the latter. The olivary columns, however, are in great part continuations of the thalami on the one hand, and of the gray matter of the cord on the other; and contain abundance of vesicular matter, in which nerves are implanted.

And it must be admitted, that the intimate connexion of sensation and motion, whereby sensation becomes a frequent excitor of motion,—and voluntary motion is always, in a state of health, attended with sensation,—would *à priori* lead us to look for the respective centres of these two great faculties, not only in juxtaposition, but in union at least as intimate as that which exists between the corpus striata and optic thalamus, or between the anterior and the posterior horns of the spinal gray matter.

Saucerotte, Foville, Pinel Grandchamps, and others, advanced the opinion, that the corpora striata and the fibrous substance of the anterior lobes of the brain had a special influence upon the motions of the lower extremities, and that the optic thalami and the fibrous substance of the middle and posterior part of the brain presided over the movements of the upper extremities. We find, however, but little to favour the theory either in the results of experiments, in pathological observation, or the anatomy of the parts. Longet states, that, in his experiments upon the optic thalami, the paralysis affected equally the anterior and the posterior extremities. Andral analysed seventy-five cases of cerebral lesion limited to the corpus striatum or optic thalamus. In twenty-three of these cases, the paralysis was confined to the upper extremity: of these, *eleven* were affected with lesion of the corpus striatum or of the anterior lobe; *ten* with lesion of the posterior lobe, or of the optic thalamus; the *two* with lesion of the middle lobe.* Hence it is plain that a diseased state of the corpus striatum is as apt to induce paralysis of the upper extremity, as lesion of the thalamus; and we are forced to conclude, that pathological anatomy is not competent to decide the question. Lastly, the anatomy of these two bodies renders it highly improbable that they perform a function so similar, as that of directing the movements of particular limbs. The great size of the optic thalamus, its multitude of fibrous radiations, its extensive connexions both in the medulla oblongata and in the hemispheres by means of commissural fibres, the marked difference of its structure from that of the corpus striatum, its connexion more with the posterior horns of the spinal gray matter than with the anterior ones, and its intimate relation

* Clin. Med. t. v.

to nerves of sensation, are, in our judgment, sufficient anatomical facts to warrant the opinion that the thalami must perform a function which, although it may be subservient to, or associated with, that of the striated bodies, is yet entirely dissimilar in kind.

It has been supposed that the corpora striata are special centres or ganglia to the olfactory nerves, and to the sense of smell. But such a supposition is altogether superfluous, inasmuch as a very distinct and obvious centre to these nerves exists in the olfactory process or lobe, miscalled *nerve* by descriptive anatomists. The small olfactory nerves are implanted in the anterior extremity or bulb of this process, which is provided with all the structural characters of a nervous centre, and contains a ventricle. This lobe, moreover, is always developed in the direct ratio of the size and number of the olfactory nerves, and of the development of the sense of smell; and in the Cetacea, a class in which the olfactory nerves and process either do not exist at all, or are so imperfectly developed as to have escaped the notice of some of the ablest anatomists, the corpora striata are of good size proportionally to that of the entire brain.

Corpora Quadrigemina.—The marked connexion of these gangliform bodies with the optic nerves plainly indicates that they bear some special relation to those nerves, and to the sense of vision; and this indication becomes more certain when we learn, from comparative anatomy, that in all vertebrate tribes in which the encephalon is developed, special lobes exist, bearing a similar relation to the optic nerves (pp. 274—5). When the optic nerves are large, these lobes are large; and in the Pleuronecta, in which the eyes are of unequal size, Gottsche states that the optic lobes are unequal. Still, as Serres has remarked, the quadrigeminal tubercles probably perform some other office besides that which refers to vision; inasmuch as the absence, or extremely diminutive size, of the optic nerves in some animals (the mole for instance) does not materially affect that of these bodies.*

Flourens found that destruction of either of these tubercles on one side was followed by loss of sight on the opposite side, and consequently that the removal of both deprived the animal altogether of the power of vision, but did not affect its locomotive or intellectual power, nor its sensibility, except to light. In these experiments the action of the iris was not impaired if the tubercles were only partially removed; as long as any portion of the roots of the optic

* Cyclop. Anat., art. *Optic nerves.*

nerves remain uninjured, the iris continued to respond to the stimulus of light, but the total removal of the tubercles paralysed the irides. If the lobes of the brain and cerebellum were removed, leaving the tubercles untouched, the irides would continue to contract. These experiments leave no room to doubt that the optic tubercles are the encephalic recipients of the impressions necessary to vision, which doubtless are simultaneously felt by means of the optic thalami; and that they are the centres of those movements of the iris which contribute largely not only to protect the retina, but likewise to increase the perfection of vision. The optic nerve is at once the nerve of vision, and the excitor of motor impulses which are conveyed to the iris by the third nerve, which takes its origin very near to the optic tubercles. It is interesting to add, that irritation of an optic tubercle on one side causes contraction of both irides:—this is quite in accordance with the well-established fact, that, if light be admitted to one eye so as to cause contraction of its pupil, the other pupil will contract at the same time. So simultaneous is the action of the two centres; so rapid must be the transmission of the stimulus from one side to the other.

When the injuries inflicted on these tubercles were deep, more or less general convulsive movements were produced; if one tubercle were injured, the opposite side only was so affected. These convulsions were due to the lesion of the central parts of the medulla oblongata, with which the optic tubercles are intimately connected. A remarkable vertiginous movement was likewise caused, the animal turning to the side from which the tubercle had been removed. It does not appear that this rotation could be attributed to any special influence of the medulla oblongata, but rather to a state of vertigo induced by the partial destruction of vision; for Flourens found that the same effects could be produced in pigeons by blindfolding one eye. The movements, however, were not so rapid, nor did they continue so long. And Longet saw the same movements in pigeons in which he had evacuated the humours of one eye.*

It may be remarked, that deep injuries to the quadrigeminal tubercles are very likely to affect the only commissural connexion between the cerebrum and cerebellum (*processus cerebelli ad testes*), the integrity of which must doubtless be essentially necessary to ensure harmony of action between these two great nervous centres.

* Flourens' experiments have been amply confirmed by those of Hertwig and Longet.

There are many instances on record in which blindness was coincident with pathological alteration of structure in one or both quadrigeminal tubercles. In some of the cases where the lesion extended to parts seated beneath the tubercles, disturbed movements were observed, as in the experiments above related.

We are ignorant of the object of the extensive connections of the optic tracts with the tuber cinereum, the crura cerebri, and the corpora geniculata; but these points are highly worthy of future inquiry, especially with reference to the office of these last-named bodies, which is at present involved in much obscurity. Many of the fibres of the optic tracts are undoubtedly commissural between the corresponding points of opposite sides, and exist when those which form the optic nerves are deficient.

We see, then, in the quadrigeminal tubercles, centres, which, whatever other functions they may perform, have a sufficiently obvious relation to the optic nerves, the eye, and the sense of vision. This is clearly indicated by anatomical facts, by the results of experiment, and by the phenomena of disease. These bodies may, therefore, be justly reckoned as special ganglia of vision; and we are led to seek for similar centres in connexion with the other senses. The olfactory processes seem very probably to perform a similar office in reference to the sense of smell. Their structure, their relation to the olfactory nerves, and their direct proportion of bulk to that of these nerves, and to the development of the olfactory apparatus, place this question beyond all doubt. It is not so easy to determine the special ganglia of hearing; but the olivary bodies, or the small lobules connected with the crura cerebelli called by Reil *the flocks,* may be referred to as bearing a sufficiently close anatomical relation to the auditory nerve to justify our regarding either of them as well calculated to perform this function. And, with respect to touch, the ganglia on the posterior roots of the spinal and the fifth nerves may perhaps be considered in the same light; for this sense being diffused so universally, in various degrees, over the whole surface of the body, and being seated in a great number of different nerves, would need ganglia in connexion with all those nerves which are adapted to the reception of tactile impressions. The analogous sense of taste has its ganglia in those of the glosso-pharyngeal and the fifth.*

* It may be urged against this conjecture respecting the functions of the ganglia of the spinal nerves and the fifth, that the analogy between these bodies and the quadrigeminal tubercles is incomplete, inasmuch as the optic nerves are probably *implanted* in the latter, but the nerves of touch merely

The upper and posterior part of the mesocephale has already been referred to, as being most probably that part of the brain which is most directly influenced by emotional excitement. Dr. Carpenter appears to localize the seat of emotional influence more specially in the corpora quadrigemina, and refers to certain fibres, which he considers terminate in those bodies, as channels of emotional impulses. Although we cannot agree with this able writer in this limitation of the centre of emotion (so to speak), nor in the existence of a distinct series of fibres for emotional acts, we think the arguments he advances are most applicable to that view which refers the influence of emotion to the gray matter of this entire region, which is brought into connexion with the spinal cord by the fibres of the anterior pyramids, as well as probably through the continuity of the olivary columns and the posterior horns of the spinal gray matter.

Every one has experienced in his own person how the emotions of the mind, whether excited by a passing thought, or through the external senses, may occasion not only involuntary movements, but subjective sensations. The thrill which is felt throughout the entire frame when a feeling of horror or of joy is excited, or the involuntary shudder which the idea of imminent danger or of some serious hazard gives rise to, are phenomena of sensation and motion excited by emotion. The nerves which take their origin from the medulla oblongata, mesocephale, or crura cerebri, are especially apt to be affected by emotions. The choking sensation which accompanies grief is entirely referrible to the pharyngeal branches of the glosso-pharyngeal and vagi nerves, which come from the olivary columns. The flow of tears which the sudden ocurrence of joy or sorrow is apt to induce may be attributed to the influence of the fifth nerve, which is also implanted in the olivary columns, upon the lacrymal gland; or of the fourth nerve, which anastomoses with the lacrymal branch of the fifth. The more violent expressions of grief, sobbing, crying, denote an excited state of the whole centre of emotion, involving all the nerves which have connexion with it, the portio dura the fifth, the vagus, and glosso-pharyngeal; and even the respiratory nerves, which take their origin from the spinal cord, as the phrenic, spinal accessory, &c. And laughter, "holding both his sides,' causes an analogous excitation of the same parts of the central organ and of the same nerves. The very different effect produced by the

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pass through the former. But, in truth, we know so little of the positive relation of the nerves in question to the ganglia, that no argument, either for or against the above view, can rest upon such imperfect information.

excitement of the same parts must be attributed to the different nature of the mental stimulus.

As the passing thought—the change wrought during the exercise of the intellect—may excite the centre of emotion, so this latter may exert its influence upon the general tenor of the mind, and give to all our thoughts the tinge of mirth or sadness, of hope or despondency, as one or the other may prevail. We say of one man, that he is constitutionally morose; of a second, that he is naturally gay and mirthful; and of a third, that he is a nervous man, and that he is not likely to be otherwise. One man allows his feelings to hurry him on to actions which his intellect condemns; whilst another has no difficulty in keeping all his feelings in entire subjection to his judgment. "Of two individuals with differently constituted minds," remarks Dr. Carpenter, "one shall judge of everything through the medium of a gloomy morose temper, which, like a darkened glass, represents to his judgment the whole world in league to injure him; and all his determinations, being based upon this erroneous view, exhibit the indications of it in his actions, which are themselves, nevertheless, of an entirely voluntary character. On the other hand, a person of a cheerful, benevolent disposition, looks at the world around as through a Claude-Lorraine glass, seeing everything in its brightest and sunniest aspect, and, with intellectual faculties precisely similar to those of the former individual, he will come to opposite conclusions; because the materials which form the basis of his judgment are submitted to it in a very different form." Such examples abundantly illustrate the important share which the emotions take in the formation and development of character, and how all things presented to the mind through the senses may take their hue from the prevailing state of the feelings. If a certain part of the brain be associated with emotion, it is plain that that part must be in intimate connexion with the seat of change in the operations of the intellect, in order that each may affect the other; that the former may prompt the latter, or the latter excite or hold in check the former. And this association of the emotions with a certain portion of the brain explains the influence of natural temperament, and of varying states of the physical health, upon the moral and intellectual condition of individuals. We may gather from it how necessary it is to a well-regulated mind, that we should attend not to mental culture only, but to the vigour and health of the body also; that to ensure the full development of the *mens sana*, we must secure the possession of the *corpus sanum*.

Certain diseases are evidently associated with disturbed or excited states of emotion. In such cases, the nerves most affected are those connected with the mesocephale and medulla oblongata, denoting an excited state of those portions of the encephalon. Of these diseases the most remarkable are *hysteria* and *chorea;* both of which may be induced either by a cause acting primarily upon the mind, or by functional disturbance of the body, as deranged assimilation, in persons of a certain character of constitution. In hysteria, the globus, the tendency to cry or laugh, the disturbed breathing, the variously deranged state of the respiratory acts, all denote affection of most, if not all, the nerves coming from those segments. In chorea the frequent movements of the face and eyes, the peculiar and very characteristic mode of protruding the tongue, the impaired power of articulation, are dependent on an altered state of that part in which the portio dura of the seventh pair, the third, fourth, and sixth, and the ninth nerves are implanted. In both diseases the principal central disturbance is in the mesocephale; and that may be caused either by the direct influence of the mind upon it, or by the propagation of a state of irritation to it from some part of the periphery. Chorea, even of the most violent and general kind, is very commonly produced by sudden fright; and it is well known how frequently mental anxiety or excitement develops the paroxysm of hysteria.

There is no part of the cerebro-spinal centre which appears to exercise such extensive sway over the movements and sensations of the body as this portion, the mesocephale, which we regard as the centre of emotional actions. Its influence extends upwards to the cerebral convolutions—backwards to the cerebellum — downwards to all the nerves of sensation and motion. Through its connexion with the posterior horns of the spinal gray matter, it can excite the sensitive as well as the motor nerves of the trunk. Hence it is not to be wondered at that a highly disturbed state of this centre is capable of deranging all the sensitive as well as motor phenomena of the body, and even the intellect. Hence we may explain the extraordinary movements in hydrophobia and general chorea, in both of which diseases this part of the nervous centre is doubtless affected. It has often been remarked how much more powerful are the voluntary actions when prompted by some strong emotion, than when excited only by an effort of the will. Rage, or despair, is able to magnify the power of the muscles to an incalculable degree. This may be due to the increased stimulus derived from the influence of the centre of emotion being conjoined with that of the centre of volition.

The intimate connexion of the olivary columns with the gray matter of the cord, and through that with all the roots of the spinal nerves, illustrates the power of emotional changes upon the organic processes. How often does the state of the feelings influence the quantity and quality of the secretions, no doubt through the power of the nerves over the capillary circulation! Blushing is produced through an affection of the mind, acting primarily on the centre of emotion, and through it on the nerves, which are distributed to the capillary vessels of the skin and the face.

The sexual passion must be ranked among the mental emotions. Like them, it may be excited and ministered to by a certain line of thought, or by particular physical states of the sexual organs. It seems, therefore, more correct to refer this emotion to the common centre of all, than to a special organ — according to Gall's theory; and it may be remarked, that great development of this part of the brain is just as likely to produce great width of cranium in the occipital region as a large cerebellum.

Of the Functions of the Cerebellum.—All anatomists are agreed in admitting, in the whole vertebrate series (the amphioxus excepted), the existence of a portion of the encephalon which is analogous to the cerebellum. This extensive existence of such an organ indicates its great physiological importance, as a special element of the encephalon. The cerebellum exhibits much difference both as regards size and complexity of structure in the different classes; and although, upon the whole, it increases in its development in the same ratio as the hemispheric lobes, it exhibits no constant relation of size to those parts.

The large size and complicated structure of this organ in the higher vertebrate animals, and its distinctness from the other parts of the brain,—for its commissural connexions are not extensive,—have excited the interest and curiosity of speculative physiologists; and, accordingly, we find no part respecting which a greater variety of hypotheses have been suggested, most of them being entirely devoid of foundation. The experiments of Flourens have, however, thrown more light on this subject than any previous observations; and his hypothesis appears to us nearer the truth than any which has been proposed. We shall content ourselves with examining this theory, as well as that of Gall, which assigns the cerebellum as the organ of the sexual instinct.

The facility with which the cerebellum may be removed or injured, especially in birds, without involving the other segments of the brain, renders it a much more favourable object for direct experiment than them. A skilful operator may remove the greater part or the whole of the cerebellum without inflicting any injury on the hemispheres or other parts.

Flourens removed the cerebellum from pigeons by successive slices. During the removal of the superficial layers there appeared only a slight feebleness and want of harmony in the movements, without any expression of pain. On reaching the middle layers an almost universal agitation was manifested, without any sign of convulsion: the animal performed rapid and ill-regulated movements; it could hear and see. After the removal of the deepest layers, the animal lost completely the power of standing, walking, leaping, or flying. The power had been injured by the previous mutilations, but now it was completely gone. When placed upon his back; he was unable to rise. He did not, however, remain quiet and motionless, as pigeons deprived of the cerebral hemispheres do; but evinced an incessant restlessness, and an inability to accomplish any regular or definite movement. He could see the instrument raised to threaten him with a blow, and would make a thousand contortions to avoid it, but did not escape. Volition and sensation remained; the power of executing movements remained; but that of co-ordinating these movements into regular and combined actions was lost.

Animals deprived of the cerebellum are in a condition very similar to that of a drunken man, so far as relates to their power of locomotion. They are unable to produce that combination of action in different sets of muscles which is necessary to enable them to assume or maintain any attitudes. They cannot stand still for a moment; and, in attempting to walk, their gait is unsteady, they totter from side to side, and their progress is interrupted by frequent falls. The fruitless attempts which they make to stand or walk is sufficient proof that a certain degree of intelligence remains, and that voluntary power continues to be enjoyed.

Rolando had, previously to Flourens, observed effects of a similar nature consequent upon mutilation of the cerebellum. In none of his experiments was sensibility affected. The animal could see, but was unable to execute any of the movements necessary for locomotion.

Flourens' experiments have been confirmed by those of Hertwig in every particular, and they have been lately repeated with similar results by Budge and by Longet. The removal of part of the cerebellum appears capable of producing the same vertiginous affection which has been already noticed in the case of deep injuries to the mesocephale. After the well-known experiments of Majendie, of dividing either crus cerebelli, the animal was seen to roll over on its long axis towards the side on which the injury was inflicted.

The effects of injuries to the cerebellum, according to the reports of the experimenters above referred to, contrast in a very striking manner with those of the much more severe operation of removing the cerebral hemispheres. "Take two pigeons," says M. Longet, "from one remove completely the cerebral lobes, and from the other only half the cerebellum; the next day, the first will be firm upon his feet, the second will exhibit the unsteady and uncertain gait of drunkenness."

Experiment, then, appears strikingly to favour the conclusion which Flourens has drawn, namely, that the cerebellum possesses the power of co-ordinating the voluntary movements which originate in other parts of the cerebro-spinal centre, whether these movements have reference to locomotion or to other objects.

That this power is mental, *i.e.*, dependent on a mental operation for its excitation and exercise, is rendered probable from the experience of our own sensations, and from the fact that the perfection of it requires practice. The voluntary movements of a new-born infant, although perfectly controllable by the will, are far from being co-ordinate: they are, on the contrary, remarkable for their vagueness and want of definition. Yet all the parts of the cerebro-spinal centre are well developed, except the cerebellum and the convolutions of the cerebrum. Now, the power of co-ordination improves earlier and more rapidly than the intellectual faculties; and we find, in accordance with Flourens' theory, that the cerebellum reaches its perfect development of form and structure at a much earlier period than the hemispheres of the cerebrum.

It may be stated, as favourable to this view of the mental nature of the power by which voluntary movements are co-ordinated, that, in the first moments of life, provision is made for the perfect performance of all those acts which are of the physical kind. Thus, respiration and deglutition are as perfect in the new-born infant as in the full-grown man; and the excitability of the nervous centres to physical impressions is much greater at the early age, partly perhaps in consequence of the little interference which is received at that period from the will.

That the cerebellum is an organ favourably disposed for regulating and co-ordinating all the voluntary movements of the frame, is very apparent from anatomical facts. No other part of the encephalon has such extensive connexions with the cerebro-spinal axis. It is connected slightly indeed with the hemispheres of the brain, but most extensively with the mesocephale, the medulla oblongata, and the spinal cord. Now it is not unworthy of notice that its connexion with the brain proper is more immediately with that part which we regard as the centre of sensation; namely with the optic thalami, through the processus cerebelli ad testes. And it cannot be doubted that the muscular sense materially assists in the co-ordination of movements.

The cerebellum is connected with the medulla oblongata and spinal cord by the restiform bodies, and the posterior columns of the cord, and with the mesocephale by the fibres of the pons. Thus this organ is brought into union with each segment of the great nervous centre, upon which all the movements and sensations of the body depend. It would be difficult to conceive any other affection for which so elaborate a provision would be necessary, excepting that of regulating and co-ordinating the infinitely complex movements which the muscular system is capable of effecting; more especially when it is plain that the antero-lateral columns of the cord and the anterior pyramids and olivary columns supply all the anatomical conditions which may be necessary for the development of acts of sensation and volition.

So far, then, we derive from experiment and from anatomy arguments highly favourable to Flourens' theory of the use of the cerebellum. The results of pathological inquiry afford no satisfactory information on this point; for so closely connected are the transverse fibres of the pons with the anterior pyramids in the mesocephale, that the morbid influence of any deep-seated lesion of either hemisphere of the cerebellum is very readily transferred to that segment, and produces symptoms precisely resembling those of lesion of either cerebral hemisphere. The signs referrible to cerebellar lesion are therefore obscured by those which result from the affection of the pyramidal bodies. A few cases, however, have been put on record in which a tottering gait, like that of a drunken man, and a defective power of co-ordination existed in connexion with a diseased state of cerebellum.*

It remains for us to notice the celebrated theory of Gall, that the instinct of propagation has its seat in the cerebellum; which, indeed, according to the author of the theory, and the majority of his followers of the phrenological school, is exclusively devoted to that function.

* Andral, Clin. Med. t. v. p. 428.

We conceive that this view is far from admissible, on several grounds, of which the following deserve particular mention.

1. It is extremely questionable how far the sexual instinct admits of being separated from the emotions — from those especially which are clearly instinctive in their nature; and, even if it were separable from them, it seems scarcely of such importance, when compared with the other instincts, as to need a separate organ of great magnitude and of complex structure. If we compare it, for example, with the instinct of self-preservation, as manifested in providing either for the wants of the body, or for defence against assault, it certainly cannot be admitted to have a superior influence in the animal œconomy to this the most pressing of all. Yet it is not pretended to assign a separate seat even to this.

2. The nature of the generative instinct is scarcely such as to require in its central organ connexions so extensive as those possessed by the cerebellum. It is not likely that this organ would be connected with any other part of the spinal cord than that from which nerves are derived to the organs of generation: nor is it conceivable that an instinct like this should require for its exercise fibrous matter in such large quantity as exists in the cerebellum, taking its rise from so great a surface of vesicular matter.

3. The generative instinct is not so pre-eminently developed in man as to account for the great superiority in size, as well as structure, of the human cerebellum over that of the lower animals, even of the mammiferous class. On the contrary, it may be safely asserted that this instinct is much more powerful in the monkeys, and also in the frogs; in the latter of which the cerebellum is absolutely very small, and especially so, relatively to the spinal cord and the cerebral lobes.

4. If the cerebellum be the seat of the generative instinct, it ought to exhibit marked indications of wasting, in cases where the genital organs have been mutilated; or where they have decayed in the natural progress of age. Yet the recorded cases of this nature are by no means conclusive; on the contrary, M. Leuret's remarkable observations shew, that, in the gelding, the cerebellum is actually heavier than in either the stallion or the mare.

5. It does not appear, from pathological research, that the cerebellum has any peculiar influence upon the genital organs. Injury or disease of that organ very rarely produces any effect upon the penis; but lesion of the medulla oblongata or of the spinal cord is very apt to occasion a semi-erection of that organ.

Of the Convolutions of the Brain. — These, with the fibrous matter which connects them with the optic thalami and corpora striata, form by far the largest portion of the encephalon; and this fact alone ought to stamp them with great physiological importance. The complexity of the convolutions in the animal scale is in the direct ratio of the advance of intelligence. It must be remarked, however, that the weight of the brain, whether absolute, or in relation to the body, affords no criterion, or at best an imperfect one, of the extent of the convoluted surface. Highly complicated convolutions may exist along with a brain both absolutely and relatively small. Thus Leuret asserts, that the ferret, which has several well-marked convolutions on each hemisphere, has a brain no larger than that of the squirrel, which has no convolutions at all, and which wants even the few fissures which mark their first development in the rabbit, the beaver, the agouti, etc. And the last-named animals have the brain both absolutely and relatively larger than that of the cat, the pole-cat, the roussette, the unau, the sloth, and the pangolin, all of which possess convolutions. We hence learn the physiological distinctness of these organs from the more deeply-seated gangliform bodies of the brain to which we have already seen that separate functions may be assigned.

At the early periods of human life, in infancy and childhood, the convolutions of the brain are very imperfectly developed, and their increase of size goes on simultaneously with the advance of mental power. If the former be arrested, or if some congenital fault prevent the further growth of the convolutions, the mental powers are of the lowest and feeblest kind, but little above those of the brute with imperfect convolutions. In all idiots the brain is not only small, but its convoluted surface is extremely limited.

We remark, here that the convoluted form must be regarded no otherwise than as a convenient mode of packing, which affords an indication of a greater or less superficial extent of vesicular matter, for in cases where a slow and gradual accumulation of water takes place within the ventricles of the brain, when accompanied with corresponding enlargement of the cranium, the convolutions become unfolded; and yet the intellect may remain unimpaired, at least so far as the obvious damage to the *quality* of the nervous matter in such cases will allow.

In examining the brains in the animal series, we observe a progressive increase in the complication of the convolutions, and therefore in the extent of the convoluted surface, as we pass from the inferior to the higher classes,—from those endowed with but feeble intelligence to those which enjoy sagacity, docility, and memory.

Instances have been already referred to of animals of the same group, although of different species, having brains very differently developed as regards the convoluted surface. In the animal with greater mental power, the convolutions are always deeper or more complex (*vid.* p.283).

If a similar comparison were instituted between the brains of different men, whose intellectual powers had been known, there can be no doubt that a similar result would be obtained. A series of outline views of the convolutions of the brain in various known individuals would be of great interest and advantage in reference to the question of their function.

Thus anatomy leads to the conclusion that the operations of the mind are associated with the convolutions. Perception, memory, the power of abstraction, imagination, all possess, as instruments of corporeal action, these folds of vesicular and fibrous matter. These parts, in the language of Cuvier, are the sole receptacle in which the various sensations may be as it were consummated, and become perceptible to the animal. It is in these that all sensations take a distinct form, and leave lasting traces of their impression; they serve as a seat to memory, a property by means of which the animal is furnished with materials for his judgments.*

It is quite established as the result of all the experiments upon the cerebral convolutions and the white matter of the centrum ovale, that mechanical injury to them occasions no pain, nor disturbance of motion. The endowments of the nerve-fibres which form the fibrous substance of the cerebral convolutions appear to be quite distinct from those of sensitive or motor nerves. They are internuncial between parts which are beyond the *immediate* influence of the ordinary physical agents, and which have no direct connexions with muscular organs. And if, under the influence of morbid irritation, they do excite pain or convulsion, which is frequently the case in disease of the cerebral meninges, this is effected through a change produced in the corpora striata or optic thalami propagated to the origins of motor and sensitive nerves.

The recorded experiments upon the removal of the hemispheres of the brain do not lead to any satisfactory conclusion, as in all of them the corpora striata and thalami have been removed at the same time. But it may be here stated, that the effect of the removal of the hemispheres in Flourens' experiments was to throw the animal into a state of deep sleep, retaining its full muscular power, yet apparently inca-

* Cuvier, Report sur le Mémoire de Flourens sur le Système nerveux.

pable of a single mental nervous action, whether voluntary or sensitive.

When the membranes of the brain are in a state of inflammation, disturbance of the mental faculties is an invariable accompaniment to an extent proportional to the degree of cerebral irritation, and more especially so when the inflammation is seated in the pia mater of the convolutions. This disturbance of mind is frequently indicated by the manifestation of delirium of a more or less violent kind. It is plain that in such a case, the delirium arises from the altered state of the circulation in the gray matter of the convolutions, the blood-vessels of which are immediately derived from those of the pia mater, so that the one cannot be affected without the other likewise suffering. And it may be stated, as a fact no less interesting in a physiological than important in a practical point of view, that in many, if not in most, instances of violent delirium, such, for example, as delirium tremens, the vesicular matter of the convolutions is found after death to be bloodless, as if its wonted supply of blood had been completely cut off from it. Thus it happens in the delirium after great operations — in that of rheumatic fever — and perhaps also of gout — and in that which occurs in the more advanced stages of continued fever.

We learn from the most trustworthy reports of the dissections of the brains of lunatics, that there is invariably found more or less disease of the vesicular surface, and of the pia mater and arachnoid in connexion with it, denoted by opacity or thickening of the latter, with altered colour or consistence of the former.

From these premises it may be laid down as a just conclusion, that the convolutions of the brain are *the centre of intellectual action*, or, more strictly, that this centre consists in that vast sheet of vesicular matter which crowns the convoluted surface of the hemispheres. This surface is connected with the centres of volition and sensation (corpora striata and optic thalami), and is capable at once of being excited by, or of exciting them. Every idea of the mind is associated with a corresponding change in some part or parts of this vesicular surface; and, as local changes of nutrition in the expansions of the nerves of pure sense may give rise to subjective sensations of vision or hearing, so derangements of nutrition in the vesicular matter of this surface may occasion analogous phenomena of thought, the rapid development of ideas, which, being ill-regulated or not at all directed by the will, assume the form of delirious raving.

The actions of the convoluted surface of the brain, and of the fibres connected with it, are altogether of the mental kind. The physical changes in these parts give rise to a corresponding manifestation of ideas; nor is it likely that any thought, however simple, is unaccompanied by change in this centre. The shock of concussion so far checks the organic changes of the vesicular surface, and perhaps, also, of the fibrous matter, as to interrupt for a time those conjoint actions of the mind and the brain which are necessary for perfect consciousness. The condensation of the substance of the hemispheres which is produced by an apoplectic clot, or by the effusion of some other foreign matter, prevents a similar consent of action, and thus gives rise to the phenomena of *coma,* in which all mental nervous actions are destroyed or suspended. Those parts of the cerebro-spinal centre on which the physical actions depend, being more completely protected from compression, do not suffer in their functions, and, consequently, actions of this kind remain unimpaired.

This view of the function of the convolutions of the brain has been held by nearly all the great anatomists who have directed their investigations to this wonderful organ. Our countryman, Willis, distinctly advanced this opinion in the seventeenth century, and conjectured that the various gyrations were intended for retaining the animal spirits "for the various acts of imagination and memory" within certain limits. The distinguished Gall, however, proposed to assign certain convolutions as the seat of certain faculties of the mind — moral feelings, or instinctive propensities — and upon this basis raised the celebrated theory of Phrenology, which has been pursued since his time with all the zeal and interest naturally attaching to a science, which professes from external signs to detect the natural tendencies of the spirit within.

We do not propose to discuss the validity of this theory, which seems to have been taken up with more apparent zeal for victory, than love of truth. But we shall remark, that, in considering the truth or falsehood of Phrenology, it is absolutely necessary to separate the metaphysical question — as to the existence of certain faculties of the mind — from what has been admitted as a physiological fact before the foundation of the phrenological school, that the vesicular surface of the brain is the prime physical agent in the working of the intellect. A physiologist may hold the validity of this latter doctrine, and yet think as we do, that many of the so-called faculties of the phrenologists are but phases of other and larger powers of the mind; and that the psychologist must determine what are, and what are not, fundamental faculties of the mind, before the physiologist can venture to assign to each its local habitation. The empirical method, by which Gall first fixed upon certain parts of the brain as the seat of certain faculties, is exposed to this serious fallacy, that a part on the surface of the brain may appear largely developed, by reason of the large size of some subjacent or neighbouring part. We have already shewn how this may be the case with reference to the cerebellum, and that a thick neck and large occipital region may, and probably do, indicate a large mesocephale more frequently than a large cerebellum. At the same time we think that all observation, both in man and in the lower animals, proves that the energy of any nervous centre always bears a direct proportion to its bulk, whether absolute or relative; and that the phrenologists do not err in attaching great and primary importance to the size of those parts with which they associate certain faculties: while the attention which recent writers of that school have paid to the temperaments of the individuals under examination, is a proof of their admission that the *quality* of the nervous matter constitutes a highly important element in the development of nervous power.*

We have seen that the convoluted vesicular surface, and the fibres of the centrum ovale, are the seat of those physical changes which accompany, and are necessary to, intellectual action. A large number of these fibres is commissural, but the greatest proportion of them serves to establish a communication between the centre of intellectual action, and the centres of volition and sensation. Through the connexion with the former the intellect may prompt or excite the will; and the will, on the other hand, may control, direct, or apply the powers of the intellect. The faculty of Attention, and, therefore, in a certain degree, the power of Memory, are dependent on the influence of the centre of volition upon the centre of intellectual action. Every one is sensible of a power which he possesses of fixing his attention on any given subject, as distinct as that by which he can contract any particular muscle. Again, the association of the intellectual centre with that of sensation is necessary to ensure the full perception of sensitive impressions. The experience of each individual can supply him with numberless instances in which, while the mind was employed upon some other object of interest, an impression was made upon some one of the organs of sense, and indistinctly *felt*, but not fully

* Carus has lately propounded a new Cranioscopy, founded upon the tripartite composition of the cranium, which bids fair to rival the system of Gall. See a Lecture in Lond. Med. Gazette, vol. xxxiv., translated by Dr. Freund.

perceived. When the mind has become disengaged, the fact that an impression had been made is remembered, without any ability to recollect its precise nature. And in many lunatics the centre of intellectual action is so impaired as to destroy or greatly reduce the power of perception, whilst there is abundant evidence to shew that the affections of the organs of sense still make a sufficient impression on the centre of sensation. In some cases, however, this centre likewise participates in the general hebetude.

Perfect power of speech, that is, of expressing our thoughts in suitable language, depends upon the due relation between the centre of volition and that of intellectual action. The latter centre may have full power to frame the thought; but, unless it can prompt the will to a certain mode of sustained action, the organs of speech cannot be brought into play. A loss of the power of speech is frequently a precursor of more extensive derangement of sensation and motion. In some cases the intellect seems clear, but the patient is utterly unable to express his thoughts; and in others there is more or less of mental confusion. The want of consent between the centre of intellectual action and of volition, is equally apparent in cases of this description, from the inability of the patients to commit their thoughts to writing.

The hemispheres of the brain, as has been already stated, are insensible to pain from mechanical division or irritation; in wounds of the cranium in the human subject, pieces of the brain which had protruded have been removed without the knowledge of the patient. Nevertheless, pain is felt in certain lesions of the brain, even when seated in the substance of the hemispheres, or in the optic thalami or corpora striata. This results from the morbid state affecting other parts with which nerves are connected, as the medulla oblongata; or in which nerves are distributed, as the membranes. The nearer a cerebral lesion is to the membranes or to the medulla oblongata, the more likely is it to excite pain. Headaches, of whatever nature, must be referred to irritation, either at their centres or at their periphery, of those nerves which are distributed in the dura mater, or in the scalp. The branches of the fifth pair, of the occipital nerve, and the auricular branch of the cervical plexus, are those most frequently affected.

Certain sensations are referred to the head which may occur from a morbid state, or may be produced by changes of position in the body. Such are, vertigo, a sense of fulness, or of a weight in the head, a feeling of a tight cord round the head. These are, no doubt, truly subjective, arising from alterations in the distribution or in the quality of the blood sent to the brain. A sensation of a rushing of blood to the head is often consequent upon excessive hemorrhage, or accompanies a state of extreme debility from any cause. This is owing in great part to the feeble tone of the arteries, resisting imperfectly the flow of blood to the head, and allowing it to impress the nervous matter too much. It is well known, that, by turning round quickly on one's own axis, the sense of *vertigo* may be produced,—a confused feeling in the head, and an inability to maintain perfectly the balance of the body, accompanied by an appearance as if external objects were revolving. If the eyes be kept shut, the uneasy feeling of the head will take place, but no true vertigo. To obtain this feeling perfectly, the eyes must be open, and objects presented to them. And Purkinje has shewn that the direction in which external objects appear to revolve is influenced by the position of the body and of the head while turning round, and by the position of it afterwards, when the experimenter has ceased to move round. If the experimenter have kept his head in the vertical position while moving round, and afterwards when standing still, the objects appear to revolve in the horizontal direction. If the head be held with the occiput upwards while turning round, and then erect when standing still, the objects seem to rotate in a vertical plane, like a wheel placed vertically revolving round its axis.* It is highly probable that these sensations, as well as those which arise spontaneously, are due to some irregular distribution of blood to various parts of the brain. A sense of giddiness frequently precedes fainting, and is attributable to the temporary deficiency in the supply of blood to the head. If the horizontal position be immediately adopted, or the body be laid with the head inclined downwards, the faint may be prevented. The sense of giddiness which is experienced upon rising from the horizontal position after illness, is doubtless of the same kind. Anæmic patients experience this feeling of giddiness even in the horizontal posture;—and both it and the headache and delirium, which accompany this state of bloodlessness, may be somewhat relieved by placing the patient on an inclined plane with the head downwards.

The mind possesses a remarkable power of exciting and of exalting painful sensations in various parts of the body. If the attention be directed very strongly, and for some time, to any part, that part may become the seat of pain, for which the most effective remedy is to engage the thoughts as much as possible on some other object.

* Müller's Physiology, by Baly, vol.i. p.848.

In many instances, where pain has been excited by a physical cause, there can be no doubt it has been continued long after the cessation of its exciting cause, by the attention of the patient having been directed to it. It is probable, that in such cases the *perceiving* parts of the brain (so to speak) become habituated to a certain condition of the centre of sensation, produced by the original exciting cause of the pain.

Nerves are implanted only in those parts of the encephalon which are capable of physical nervous actions: the convulsions of the brain, the corpus striatum, the optic thalamus, and the cerebellum, are capable only of mental nervous actions. In every change of these latter, the mind is either the excitor or the excited; the conditions of the nerves involve them only through the influence of the centres in which the nerves are implanted; and they affect the nerves only through the same medium. Matteucci's experiments as to the effects of electricity on the different parts of the brain, shewed that, as long as the current was confined to those parts which are capable only of mental actions, no apparent effect was produced. But when the poles of the battery had penetrated to the base of the brain so that the current might pass through the deeper seated parts, then the animal cried out with pain, and strong convulsions were produced.

Those parts in which physical nervous actions take place, (although capable of partaking in the mental actions,) require the excitation of physical stimuli in order to develop their peculiar phenomena, and thus have frequent remissions in the active performance of their functions in the frequent absence of the ordinary stimuli. But the ever-active mind keeps up a constant and proportionately rapid train of changes in those parts which are more especially connected with mental actions: hence these parts, requiring repose, fall at certain periods into that peculiar and inscrutable state called *sleep;* in which, whatever be the condition of the mind itself, the brain either refuses, or is slow to respond to its stimulation, or to convey impressions to it. In deep sleep we are completely unconscious, and may remain for a considerable time motionless. But as the accustomed period of repose approaches to its termination, the sleep becomes lighter, a degree of consciousness returns, and mental changes take place, which, whether incoherent or connected, constitute what are familiarly known as dreams. In lighter sleep, it cannot be said that there is complete want of consciousness; nor is the mind, although comparatively quiescent, in complete repose. The readiness with which, at times, some persons, during sleep, reply when addressed, and resume the waking state,—the power which many unquestionably have of limiting the duration of sleep to a predetermined period, as contrasted with the deep unconsciousness and slowness to awake of others,—strongly favour this idea.

This state, with which the revolution of each diurnal period makes us familiar, as one of repose to the great centres of mental nervous actions—"tired Nature's sweet restorer"—occurs, with modifications, as the result of certain morbid processes, as the effect of certain physical agents, or even as the consequence of peculiar states of mind. Thus, under the influence of pressure, from a clot of blood compressing the brain, or from lymph or fluid at its base, a state varying from that of drowsiness up to the profoundest sleep, or *coma,* may be induced. Whatever be the nature of the compressing substance, or wherever situate, if the hemispheres experience general pressure, this result will ensue. Again, a class of drugs, of the sedative or narcotic kind, exerts a similar influence; and, if given in too large a dose, will paralyse the brain. We have daily evidence of this in the effects of opium, which paralyses at first the centres of mental actions, and ultimately those of physical actions. Lastly, particular states of the system, induced, perhaps, by deranged assimilation, or by great previous disturbance of mind, dispose persons to fall into that state which is called *somnambulism.* The somnambulist is one who dreams, and acts in his dream as if he were awake, and as if all the phenomena presented to him were real. He appears to the bystanders in a deep sleep, but acts with wonderful precision, walks with steady gait, and avoids obstacles. Yet frequently accidents, injurious or even fatal, occur; which shew that on such occasions he is asleep, and has not the *full* command of his senses. Persons in this state will answer questions rationally and with readiness, and do not appear to be at all disturbed by being questioned. The hypochondriacal or hysterical diathesis disposes greatly to the development of somnambulism both in male and female.

A state remarkably analogous to this of somnambulism may be induced in persons of nervous temperament, which has been called the *Mesmeric sleep,* or trance. It requires for its production the apparent influence of another individual, who watches the person experimented on with an intent look, and makes certain movements before him, which are called *passes.* All persons are not susceptible of passing into this state, any more than they are of exhibiting the phenomena of somnambulism. The same state of constitution which disposes to the latter is favourable to the former. Remarkable statements have been made, and confirmed by the testimony of a larger number of observers, tending to imply that in these cases the faculties become exalted in an extraordinary manner; and that the individual acquires powers of a novel description, and even of a superhuman kind. It behoves all sober-minded persons to be slow to accept such statements as true, and, without impugning the veracity of the reporters, to inquire whether they do not rest more upon a misinterpretation than upon a misrepresentation of facts. The polar force of the mental nervous centres may, in this peculiar state, be so affected as to favour the development of subjective phenomena, which it is evident may assume particular forms under the influence of impressions made from time to time upon the senses. The ravings of a delirious or of a lunatic patient often take a particular direction under the influence of a question or remark let fall by some bystander; it is not unlikely that persons, with a mental bias for the marvellous, might discover in such patients quite as much evidence of superhuman power, as has been adduced by the Mesmerists.

We cannot avoid remarking, how much it is to be lamented that inquiries of so delicate a nature, affecting the very confines between mind and matter, should have usually fallen into the hands of persons ill qualified for such pursuits, either by mental constitution or by previous experience in the study of subjects involving both physical and metaphysical knowledge. Little is to be expected in such difficult researches from *dilettanti* of either sex; much less from those whose excessive zeal for novelty and notoriety must necessarily cast suspicion on their statements. Nor can we hope that truth can be elicited from experiments and observations which are made before the public gaze, with more of the characters of a theatrical exhibition than of a sober philosophical investigation.

Functions of the Commissures. — The commissures of the brain have long been regarded as provisions to ensure the harmonious co-operation of certain parts of the nervous centres, whether on the same or on opposite sides. This opinion rests mainly upon their anatomical connexions; for but little that is satisfactory can be concluded from either the comparative anatomy or pathological conditions of them. It is evident that the principal commissures bear a direct ratio in point of development to that of certain parts; and that, when those parts are imperfect or absent, the commissures are deficient or wholly wanting. Thus the corpus callosum and the hemispheres are developed together; the fornix and the hippocampi, the pons Varolii and the cerebellar hemispheres.

The anatomy of the corpus callosum favours the hypothesis that it is the bond of union to the convoluted surface of the hemispheres, and that it is the medium by which the double organic change is made to correspond with the working of a single mind. There is nothing in the recorded observations of morbid change or congenital defect of this part to militate against this idea; but it must be remarked that all these cases are accompanied with lesion or defect of other parts, which weaken the inferences to be drawn respecting the corpus callosum. Direct experiments upon this commissure yield only negative results. Longet and others found that irritation of it did not cause convulsions: and Longet states, that injury to the corpus callosum in young rabbits and dogs did not appear to disturb voluntary movements; and that, when he incised this body in its whole length in rabbits standing, they have continued to maintain that position; or, when urged on, ran; and that no convulsive movement whatever, nor any sign of pain was manifested. Such statements are certainly favourable to the supposition that these fibres are destined to connect centres whose appropriate stimulus is mental.

The fibres of the fornix manifest the same insensibility to mechanical irritants; and their obvious anatomical connexion with particular convolutions warrants but one conclusion, that they associate the actions of those parts. Lallemand relates a case in which the symptoms were altogether limited to mental disturbance, without any affection of the sensitive or motor powers, and the fornix and corpus callosum were found in a state of complete softening without discoloration.

The fibres of the pons Varolii bring the cerebellar hemispheres into connexion with each other, and with the vesicular matter of the mesocephale. Direct experiments on these fibres can yield no satisfactory result, because they are so intimately associated with the deeper seated parts of the mesocephale, and with the nerves of the fifth pair and others, that it is impossible to irritate them in the living animal without likewise irritating these other parts. And it is sufficiently evident, that these fibres have no necessary connexion with sensation and volition, from their non-existence in birds; nor even with the cerebellum *when that organ is single.* It will be borne in mind, that at a previous page we have referred to the connexion of these fibres with the mesocephale as explaining the crossed influence of lesion of one hemisphere of the cerebellum.

We conclude this chapter with the following inferences, which, we think, the present state of knowledge justifies:

1. The spinal cord contains within itself all the physical conditions necessary for the mental and physical actions of the trunk and extremities, so long as its connexion with the encephalon is perfect through the anterior pyramids.

2. There is no sufficient evidence to prove the existence of a class of sensori-volitional fibres distinct from those which are the instruments of physical actions.

3. Each segment of the cerebro-spinal centre, whether in the cranium or in the spinal canal, gives origin to its own proper nerves, and has no connexion with the neighbouring segments, otherwise than by commissural fibres or vesicular matter.

4. The antero-lateral columns of the cord, with the anterior and posterior horns of the gray matter, are the effective centres of motion and sensation of the trunk and extremities. The posterior columns are longitudinal commissures, by which the influence of the cerebellum is brought to bear on the various segments of the cord.

5. When the pyramids are in a state of integrity, the corpus striatum, certain accumulations of gray matter connected with the nerves of the medulla oblongata, the locus niger, and the anterior horns of the spinal gray matter are the centres of voluntary motion to the whole body; while the optic thalami, olivary columns, and posterior horns of gray matter are the centres of sensation.

6. The medulla oblongata, when connected to the corpora striata by the pyramidal fibres, is a centre of voluntary actions to those parts whose nerves are derived from it; and, in addition, it is the principal centre of the actions of respiration and deglutition.

7. The corpora quadrigemina are primary centres of visual impressions, and, with a large portion of the gray matter in the mesocephale, are centres of emotional actions.

8. The cerebellum is the co-ordinator of voluntary and locomotive actions.

9. The convolutions of the brain are the centres of intellectual actions, and are intimately associated with the mental phenomena of attention, association, and memory.

On the subjects discussed in this chapter, we refer to the more recent treatises on Physiology by Müller, Wagner, and Carpenter;—to Dr. Marshall Hall's writings on the Nervous System; the most important of which will be found in an octavo volume "On the Diseases and Derangements of the Nervous System," 1841; and in a quarto volume "On the Nervous System," 1843;—to Henle's General Anatomy;—Whytt on Vital Motions;—Prochaska, Annot. Academicæ;—Le Gallois, Œuvres;—Flourens sur le Système Nerveux;—

Desmoulins et Majendie sur le Système Nerveux;—Longet, Anat. et Physiol. du Système Nerveux;—Volkmann, in Müller's Archiv.;—Van Deen, sur la Physiol. de la Moëlle Epinère, and the works referred to at the conclusion of the last chapter.

Appendix to the Eleventh Chapter.—While the preceding pages were passing through the press, we were favoured, through the great kindness of Prof. Matteucci of Pisa, with several opportunities of witnessing his highly important electro-physiological experiments. As these experiments tend very much to confirm and substantiate the views expressed in Chap. IX., we subjoin here a succinct account of them.

The facts which M. Matteucci's researches have developed are the following:—1. That muscle is a better conductor of electricity than nerve, and that nerve conducts better than brain. 2. That in the muscles of living animals, as well as of those recently killed, an electric current exists, which is directed from the interior of each muscle to its surface. 3. That in frogs a current exists peculiar to the Batrachian reptiles, which proceeds from the feet to the head, and is distinct from the muscular current. 4. In continuation of Marianini's and Nobili's researches, Matteucci illustrates the effects of the inverse and direct currents in nerves of different function, and shews very strikingly the difference in the influence of the electrical stimulus upon nerves, from that of other stimuli upon these organs.

For these researches, Matteucci employed the galvanometer of Rumkorff (Paris), which is the same as that of Nobili, with the addition of a small apparatus by means of which the needles may be rendered more or less astatic, and thus the sensibility of the galvanometer may be more or less increased. But he also takes the precaution to guard against the development of currents by unequal chemical action upon the poles of the galvanometer, to have them made of plates of platina, which is not acted upon by water or saline solutions. He takes two plates of platina, about a quarter of an inch in breadth, and fixes each in a handle of wood. The plates are then soldered to the wires of the galvanometer, and both the handles and the plates are covered with a layer of sealing-wax varnish, leaving only a space of about a quarter of an inch uncovered at the extremity of each platinum plate.

The frog's leg, prepared in a certain way, is most susceptible of electric influence, and therefore may be used as a galvanometer of extreme delicacy. The skin is stripped off one lower extremity of a lively frog, and the whole length of the sciatic nerve is dissected out from among the muscles of the posterior part of the thigh; after which the thigh is cut across just above the knee, the nerve remaining attached to the knee and leg. The leg is now placed in a glass tube, in such a position that the nerve hangs loosely from the end of the tube. To use this galvanoscope, the operator holds the glass tube at the opposite extremity to that in which the leg is placed, and causes the nerve which hangs loosely from the tube, to touch at two points the electromotor element under examination. If the nerve be traversed by a current, the leg instantly contracts. This apparatus, called by Matteucci, *grenouille galvanoscopique*, is the most delicate we possess, if it be renewed from time to time. And it is capable, not only of indicating the existence of an electric current, but also of shewing, with a great degree of probability, the *direction* of that current. When the frog has become a little weakened, it almost constantly happens that the contraction takes place on *closing* the circuit, if the current pass from the nerve to the leg; but if it pass from the leg to the nerve, contraction will take place on *opening* the circuit.*

1. Matteucci's experiments upon the relative conducting power of animal substances were founded upon a law of derived currents. When a liquid, or any other body, is traversed by an electric current, and the plates of the galvanometer are plunged into it, there are immediate indications of a *derived* current, so directed in the galvanometer that the point at which it enters the coil of the galvanometer corresponds to the positive pole of the current which traverses the liquid. The derived current is always greater, as the plates of the galvanometer, plunged in the liquid, are more distant from each other. If a current be made to traverse different substances, which correspond as nearly as possible as regards shape, bulk, etc., the derived current from each will be exactly in the inverse ratio of the conducting power of the substance traversed.

Pieces of nerve, brain, and muscle, from a rabbit just killed, were selected for the comparative experiments: these were cut so as to correspond as nearly as possible in point of size and shape, and disposed as a chain on an insulating plane. Platinum wires, fixed by sealing-wax to two pieces of cork, which were held apart at a certain distance by a rod of glass which transfixed each of them, were soldered to the wires of the galvanometer, the platinum wires having been previously varnished to within a very short distance of their extremities. A current from twelve cells of a constant battery was now passed through the chain of animal substances. The platinum wires, held always at the same distance from each other, were successively brought into contact with brain, nerve, and muscle, and the deviation of the needle resulting from the derived current in each case was carefully noted. The derived current from nervous matter was always greater than that from muscle; that from brain greater than that from nerve, denoting a less conducting power in nervous matter than in muscle — in brain than in nerve. By increasing the distance between the platinum wires, a derived current may be obtained from muscle equal to that obtained from brain; and Matteucci, from this latter experiment, infers that the conducting power of muscle may be taken as four times greater than that of brain or nerve.

Another interesting experiment confirmed the results obtained from those just detailed. The current was made to traverse the whole length of a rabbit just killed and flayed; and the platinum wires, held at a constant distance, were applied successively to different parts, muscles, nerves, etc.: the current was found to traverse all parts, with such difference as was due to the different power of conduction of the different substances; that is, so as to yield a derived current of less intensity from muscle than from nerve, or from nerve than from brain.

2. To demonstrate the existence of an electric current in the muscles of animals recently killed or living, the following experiments have been adopted by Matteucci.

If a deep wound be made in a muscle of any living animal, and the nerve of the galvanoscopic frog be introduced into it, so that the nerve shall touch the cut surface at one point, and the outer surface of the muscle at the other, contractions instantly take place on completing the circuit. It is evident that

* Those who propose to employ the galvanometer in physiological experiments should carefully observe the precautions assigned by Matteucci, in the third chapter of his book, to guard against erroneous inferences.

this effect is due to an electric current developed by the muscle, because it is necessary that the nerve should touch the muscle at two points; and because, if the nerve be brought into similar contact with two points of any other body, no such effect will follow. To guard against the fallacy that might arise from contact with the blood, Matteucci shews, that if a nerve be brought into contact with a layer of blood at two different points, no evidence of an electric current will appear. In this, and all experiments with the galvanoscopic frog, it is to be rememb^ered, that the frog's leg must be held in the glass tube to insure perfect insulation. The experiment is always followed by the same results, whatever be the muscle of the animal touched, or even if muscles separated from the animal be operated on. The indications of the electric current remain longest in those animals in which muscular contractility lasts longest; in cold-blooded animals, such as fish and reptiles, Matteucci has seen the phenomena last for many hours. The current is sufficient to excite the nerve of a warm-blooded animal. The thighs of a rabbit having been removed, a long portion of the crural nerve was dissected out, and the muscles exposed. With a glass tube the nerve was raised and brought to touch the muscles at two points, when the whole limb was thrown into contraction.

So far distinct evidence was afforded by the animal galvanometer (so to speak) of the existence of a muscular current. When the frog's leg becomes a little weak, it indicates the direction of the current to be from the interior to the surface of the muscle.

In order to demonstrate the influence of this current on the galvanometer, a particular arrangement is necessary.

Several small cup-like cavities are scooped out in a piece of wood, twelve inches square, and an inch and a half thick. The wood and its little cavities are coated over with a layer of varnish, or small capsules sunk into the wood may be employed. Five or six frogs are prepared by flaying the posterior extremities, and the legs are separated by disarticulating them at the knee; which must be done with care, in order not to wound the mass of crural muscles. Next, each thigh is divided at its middle, and thus a certain number of conical masses (the lower halves of the thighs) are obtained. These must be arranged on the board in a chain. One half-thigh is placed at the edge of one of the cavities, with its apex to the cavity, and the cut surface outwards; and the chain is completed by arranging the others in a semicircle, so that the apex of one freely touches the cut surface of the other, and the piece which forms the opposite extreme of the series ought to touch the edge of another of the cavities by its cut surface. Thus a pile is formed, of which one of the extremities is the interior of the muscle, and the other its external surface. The board, with the muscular pile arranged upon it in this way, is now brought to the galvanometer, the platinum poles of which, if it be a very sensitive one, have been some time placed in distilled water; or, if not very sensitive, in a saline solution. The next step of the experiment is with a pipette, to pour into the cavities with which the extremes of the pile are connected, either water or some of the saline solution, according as the plates of the galvanometer have been immersed in either of those fluids.

The platinum poles of the galvanometer are now withdrawn from the fluid in which they had been immersed, and introduced into the fluid of either of the cavities; if no deviation of the needle follow this, they are at the same time plunged into the two extreme cavities of the pile, so as to close the circuit. A deviation of the needle takes place immediately, which varies in amount according to the number of segments which constitute the pile. Matteucci has obtained a deviation of 15°, 20°, 30°, 40°, 60°, etc., according to the number of half-thighs, supposing the frogs employed to be equally lively; he obtained 3° or 4° with two elements, 6° or 8° with four elements, and 10° or 12° with six, and so on. These numbers are obtained, using distilled water in the cavities; but the deviation may be increased considerably if a few drops of sulphuric acid be added to it, so that a pile of eight half-thighs, which gave a deviation of 15° with distilled water, will cause 50° with the acid liquid. When the fluid was slightly saline or alkaline, the same number of elements caused a deviation of 35°. In all the trials the current had the same direction —that is, from the internal part of the muscle to its surface.

The muscular current may be demonstrated with the muscles of other cold-blooded and of warm-blooded animals. In all cases, it is necessary so to arrange the elements of the pile, that the inner-surface of one segment shall be in contact with the outer surface of the next, and that the inner surface of a piece of muscle shall form one pole, and the outer surface of another piece the opposite pole.

The duration of the muscular current corresponds with that of contractility. In cold-blooded animals, therefore, it is greatest. In mammalia and birds it is very brief. Temperature has a considerable influence upon the intensity of the current. If frogs are placed for some time in a very cold medium, piles made from their muscles yield no evidence of electricity; but, if the frogs are placed in a warm medium for a short time after they have been taken from a cold one, the current of electricity obtained from their muscles will be stronger than that from a similar pile which had not been subjected to any change of temperature.

Any circumstances which enfeeble frogs, and derange their general nutrition, will diminish the power of the muscles to generate electricity, as they also impair the contractile force. Thus, Matteucci found the great heat of summer to impair materially the development of electricity. We have found the same result in frogs, which, having been kept crowded together in a small compass during the month of December, became ill-nourished, with soft, flabby muscles, full of moisture. The redder and more consistent the muscles are, as Matteucci remarks, the more distinct will be the signs of electricity.

The muscular current appears to be quite independent of the nervous system. The segments of which the piles are formed are obviously beyond the influence of the nervous centres; and Matteucci has taken great pains to remove from such segments all the larger nervous trunks and filaments distributed among the muscles without affecting the electrical current. And in frogs, in which the lower part of the spinal cord had been destroyed by burning, there was no evidence of impairment of the electric current in the muscles of the lower extremities.

Matteucci found that narcotic poisons, in moderate doses, had little or no influence upon the muscular current. On one occasion, he found it slightly increased in a frog to which a very small dose of opium had been given. In very strong doses, such as to kill the animal, the muscular current is destroyed. The influence of the narcotic gases upon the current is of no importance, with the exception of sulphuretted hydrogen, which has the effect of materially weakening its intensity.

On one occasion, we endeavoured to obtain a current from a pile composed of pieces of human muscle from a leg that had just been amputated; but the muscles were in so atrophied a condition, that the experiment failed with the galvanoscopic frog, as well with the galvanometer. We have since learned from Professor Matteucci, that he has obtained evidence of the current in human muscle under similar circumstances.

It is plain, from the statements above given, that the essential condition for the full development of the muscular current is a healthy and vigorous state of the muscles themselves, and that the nervous system contributes to the electrical phenomena only so far as it contributes to the healthy nutrition of the muscles by promoting their natural actions. The muscular current is one of the phenomena which attend the passive contraction of muscles; it disappears from dead muscle, and from living muscles which have so suffered in their nutrition as to lose their characteristic property. All external influences which materially affect the nutrition, and therefore the passive contraction of muscles, exert a corresponding effect upon the muscular current. The duration of the current after systemic death continues in the different animals just so long as the phenomena of contractility are present.

3. In the latter part of the last century, Galvani announced his celebrated experiment of causing contraction of the frog's leg by bringing its muscles in contact with the lumbar nerves. The following are the steps of this experiment: The integuments are stripped off the lower extremities, which are separated from the trunk at the middle of the back; a small portion of the lumbar region of the spine, from which the lumbar nerves emerge, is left with these nerves in connexion with the lower limbs, the pelvis having been cut away. If now the limbs be suspended by the segment of the spine, and one leg be carefully bent up, so as to bring the foot into contact with the lumbar nerve, the whole limb is convulsed at the moment of contact. The foot may be made to touch the muscles at various parts of the limb without any such effect. The contraction is general, and evidently of the same nature as that which the passage of an electric current through the lumbar nerves would produce. When the experiment is carefully tried, it is impossible that the nerve can experience any mechanical dragging, such as would produce an effect like that described. Galvani pointed out, that, in order to succeed perfectly in the experiment, it is necessary to wait until the frog has recovered from the tetanic state which is likely to ensue upon the necessary mode of preparation. He also stated, that the experiment is more likely to be successful if the frog have been previously moistened by a solution of salt; and that the contraction of the muscles may be produced if the nerve and foot are connected by a piece of muscle, and not directly. The accuracy of Galvani's observations has been fully established by Humboldt, Valli, and many modern experimenters. We have frequently repeated the experiment with the same result.

Fifty years after Galvani, Nobili* took up the same line of inquiry. Having prepared the legs of a frog according to Galvani's method as above described, he plunged the lumbar nerves into one capsule and the feet into another, the capsules being filled with water. When the poles of a galvanometer were introduced into the fluid of the capsules, a deviation of the needle followed, to the

* Bibliothèque Universelle, 1827.

extent of 5°, 10°, or 15° or more. The deviation could be increased by making a chain of frogs' legs prepared in the same way. The legs were placed on an insulating plane, so that the nerves of one touched the feet of the next, and so on. It is necessary that the extremities of this pile should be plunged into capsules filled with water. Or a pile may be made with a series of capsules containing water connected together by frogs' legs; the nerves being placed in one, and the feet in the next. With such piles a deviation of the needle to the extent of 60° may be obtained; or to a much greater extent, if, instead of distilled water, a weak solution of salt be employed to fill the capsules; or still more, if the fluid of the capsules be slightly acid.

In all these experiments the direction of the electric current was found to be constant, from the feet to the head. At the same time that the needle was made to deviate, the frogs' legs, whatever be the number constituting the pile, are thrown into contraction. It is not necessary for the production of the phenomena that the several legs should touch one another; it will suffice if they be connected by a conducting material, such as a skein of cotton moistened, wire, wet paper, or even water.

Nobili found that these signs of an electric current continued for many hours after the preparation of the animal. He distinguished the current by the title of *le courant de la grenouille, ou courant propre;* and he attributed it to a thermo-electric current caused by the unequal cooling of the nerve and muscle produced by evaporation.

It is evident, that the experiment of Nobili is essentially the same as the original one of Galvani. In the latter, the electric current was brought to act upon the nerves of the limb; in the former, upon the galvanometer.

The galvanoscopic frog may be used as a test of the electric current when Nobili's arrangement is preserved. If the extremes of the pile be connected by the nerve of the galvanoscopic limb, the instant the circuit is completed, its muscles will contract; and, as in other experiments with the galvanoscopic frog, we may determine the direction of the current when the frog becomes a little weakened.

Matteucci gives the name "*contraction propre*" to the contraction of the muscles which takes place in the frogs' legs, whether used singly or as a pile, at the same time that the deviation of the needle occurs. In order to obtain this phenomenon, the lumbar nerves must not be plunged completely in the water; otherwise the proper current circulates without passing through the nerves, and consequently the contractions do not take place, or are extremely feeble. These contractions continue, generally, only for ten or fifteen minutes, but rarely for half an hour after preparation.

Nobili has stated, that in arranging the frogs, so that the nerves of one touch those of the other, or the muscles came into contact with muscles, no contractions ensued, because, as he explained, the electro-motor elements were opposed. In Matteuci's hands, however, such a result was not obtained. If care be taken not to oppose to each other the nerves or muscles of symmetrical parts, contraction will always ensue.

The following is Matteucci's mode of shewing this remarkable experiment. The limbs of a frog are prepared in the ordinary way; but, in addition, the heads of the thigh-bones and the ilium are completely removed, so as to leave the legs connected to each other only by the nerves, through the portion of the cord which is contained in the segment of the spine which remains. The parts are placed on an insulating plane. If the muscles of one leg are made to touch the other *thigh*, contractions ensue; but not so if the leg of one side touch the *leg* of the other. Or the same effect may be produced by bringing the different parts of the limbs into connexion by moist paper or cotton; or, if the galvanometer be employed, signs of a current are afforded. by touching a thigh with one pole, and the opposite leg with the other.

In these experiments, when the frog is lively, contractions are produced, in touching the muscles of the thigh with those of the leg, as well on opening as on closing the circuit. But when it has become weak, contractions take place in one limb on closing the circuit, and in the other on opening it.

Matteucci explains the failure in producing contractions by touching corresponding parts, on the supposition, that, under such circumstances, the currents of the two limbs circulate with equal intensity, and in a contrary direction. This he proves by the following experiment: If the frogs' legs, prepared as above described, are severed from each other, and the nerve of one leg and the foot of the other are placed in one capsule filled with water, while another capsule receives the other nerve and foot; the moment the circuit is completed, strong contractions in both limbs are produced. But to the galvanometer no sign of an electric current is afforded when its poles are plunged into the capsules. "In this case," says Matteucci, "the currents of the two limbs circulate together, passing equally through the limbs; and if even the parts of the current were to take the course of the galvanometer, it is easy to see that they would circulate in it in opposite directions, and therefore would produce no deviation. If, on the contrary, the disposition of the two limbs be such that the nerves are placed in one vessel, and the feet in the other, it is easy to see that the two portions of the current which do not circulate through the animal arc, enter the extremities of the galvanometer, and circulate in it in the same direction. It is the sum of these two portions which constitutes the proper current of the frog, which sum is measured by the galvanometer.

If several frogs' legs be arranged with opposed nerves and feet in the two capsules, the effect upon the galvanometer is not increased.

Comparative experiments as to the difference of the currents in piles formed of both the lower extremities of frogs, as already described, and in piles formed of an equal number of single extremities, shewed no greater effect upon the galvanometer in the one case than the other.

From these and numerous other experiments, varied with great ingenuity and skill, Matteucci draws these conclusions:—1, that the complete electromotor element in the current of the frog is formed by one of its limbs—that is, of one leg, the thigh, its spinal nerve, and a piece of its spine;—2, that the current of one limb circulates by the other every time that, leaving the frog intact, a communication is established, in any way, between the two legs of the same frog;—3, that in the experiment by which we detect the current of the frog by the galvanometer, there is never in the wire of the instrument any other current save that which results from the sum of the two portions of the currents of the two limbs which are not discharged from limb to limb.

It is important to notice that there is no necessary connexion between nerves and muscles in the production of the proper current of the frog. Matteucci shews, by several ingenious experiments, that, although in Galvani's and Nobili's observations, the nerve and muscle were brought in contact, or were made to form conspicuous parts of the arrangement employed in the development of the phenomena, the signs of the electric current are just as distinct when the circuit is completed by the contact of other parts; or if the continuity be maintained by muscles, the main nervous trunks having been removed. Thus, if a frog be flayed, and the bones and muscles of the pelvis be cut away, so as to leave the lower extremities attached to the thorax by the lumbar nerves, contractions will be produced by bending up the leg so as to bring it in contact with the eyes, the muscles of the head, or the back. And if this frog be placed with its head in one capsule and its legs in another, the current may be detected by the galvanometer in the ordinary way. Or, if the spinal nerves and the piece of the spinal cord be removed from the lower limbs prepared in the ordinary way, the signs of the current may be obtained in the usual methods. Piles made of legs prepared in this way develop a current equally intense with that produced from piles with an equal number of elements composed of limbs with the nerves remaining. It thus appears that the electro-motor element of the current is reduced to the muscles of the leg and thigh in organic union.

So far, indeed, is the nerve from contributing to the production of the electrical phenomena, that Matteucci found that a more feeble current was developed in piles formed of the legs of frogs in which a very long portion of the nerve formed an element. He prepared the legs, leaving attached to them the lumbar and crural parts of the nerve, and formed the pile by placing the nerve on the adjacent leg, so that the communication between the segments was maintained only by the nerves. And it may be shewn further, that the nerve in, these experiments, acts only as a bad conductor of the electricity developed by the muscles; for, if the nerves be cut away, and the segments of the limbs connected by pieces of moist cotton instead, the phenomena of the pile continue unchanged.

Nothing analogous to the proper current has been found in any other reptiles but the Batrachian—nor in any other class of animals. It is not improbable, therefore, that the proper current of the frog may be due to some undiscovered peculiarity of structure in that animal.

How can we explain these remarkable electrical phenomena in the muscular current directed from the interior to the exterior of all muscles in all animals; and the proper current of the frog, directed from the feet to the head, and peculiar to the Batrachian reptiles?

It is not difficult to discover an explanation of the muscular current. The essential conditions necessary to develop the signs of this current are simply, that, by means of a conducting material, the interior of the muscular mass should be brought into communication with the exterior of the muscle, which is more or less tendinous, and covered with areolar tissue, and therefore different from the interior in structure and function. And as the signs of this current are apparent only whilst the muscle is living—that is, while it continues to display its contractile power, we may infer that the same organic conditions which are necessary to the development of contraction, are requisite for the development of electricity. Now all that is necessary for the development of the contractility of muscle is (as has been shewn in Chap. vii.) a healthy nutrition, a due supply of arterial blood, and sufficient exercise of the organ. And it would be impossible, as Matteucci remarks, not to admit that the chemical action which must be going on throughout muscle, in the constant supply and waste of which it is the seat, can be unattended with the development of electricity.

In short, the organic actions of muscle, by which the electrical current is developed, may be compared to the inorganic phenomena attending its production from the decomposition of metals. When a plate of metal,* immersed in an acidulated fluid, is oxidised by the oxygen of the water, and then dissolved in the acid, we admit that an enormous quantity of electricity is developed during this action; we add likewise, that, just as the two electrical states are disengaged, a synthesis takes place, and the effects of the previous decomposition are neutralised. It is only by means of certain arrangements that we can obtain the free electricity which is developed during chemical action. We unite to the metallic plate another which is not attacked by the water, and plunge this second plate also in the water. The circuit is thus established, and the electric current circulates in the liquid from the metal acted on to the other, and from this latter back again to the first through the metallic arc of union.

The metal acted upon in the artificial arrangement is represented, in the phenomenon of the muscular current, by the muscular fibre; the acidulated fluid is the arterial blood. The surface of the muscle, or any other conducting body not muscular fibre, but which is in contact with the muscle, represents the second plate of metal, which does not suffer chemical action, and which serves only to form the circuit. The direction of the muscular current is precisely such as it should be, supposing the current to be, as we have represented it, due to a chemical action taking place in the interior of the muscle.

The nervous system may act in two ways in connexion with this phenomenon; 1, as an imperfect conductor, which makes part of a circuit, but is not the source of electricity; it represents the electrical state of the muscular mass, interior or surface, with which it is in connexion; and 2, it acts in the conservation of the cause which disengages electricity, namely, nutrition. It is fully proved, that the integrity of the nervous system and the nutrition of the muscles, are closely leagued together; but as it cannot be admitted that the chemical action which takes place in nutrition is immediately arrested or suspended by the cutting off nervous influence, so we must allow that the muscular current may continue after the nerve has ceased to exert any control over the muscle,

The proper current of the frog does not admit of being explained upon these principles. It has been supposed, as already stated, that this current is a thermo-electric one, due to the unequal cooling of nerve and muscle, depending on the difference of evaporation in these two parts of the animal. But it has been shewn that this current persists even after the removal of the nerve; and, moreover, as Matteucci remarks, a current which is sensible to a galvanometer with a long coil, which traverses thick layers of liquid, which may be obtained by bringing muscle in contact with muscle, and which may be produced by holding animal parts in water, cannot certainly be of thermo-electric origin. It has also been supposed that this current is due to an electrochemical action; that the leg of the frog is charged with alcali or salts, whilst the thigh or the lumbar nerve contains acid. But chemical analysis of these parts affords no countenance whatever to this hypothesis. There are remarkable points of analogy between this current and the muscular current. Mat-

* Matteucci, loc. cit. p. 124.

teucci's experiments have shewn that the former has some marked connexion with muscles, and with those of the leg more especially; and he has found that the same circumstances which increase or diminish the muscular current, exert a similar influence upon the proper current. But they differ remarkably in point of duration; as the latter continues long after all traces of a muscular current have ceased to be discoverable. It is highly probable, as before stated, that the true source of this current will be found in some anatomical peculiarity of the frog.

As in the ordinary phenomena of the nutrition of muscles, by which their state of *passive* contraction or tone is maintained, electricity is developed, it is most reasonable to expect, that during *active* contraction there should be a development of electricity, as there is of heat likewise, according to Becquerel and Breschet's observations. This is shewn by Matteucci in a very beautiful experiment, which we have frequently repeated with the same results. Place a prepared frog upon an insulating plane; then prepare the leg of another frog with the crural nerve dissected out and left attached to the leg, the thigh being removed. Place the nerve of this leg upon one or both thighs of the other frog, and every time that those legs are excited to contract by a galvanic or a mechanical stimulus, contractions will be produced in the second leg, which is connected with the first only by the contact of its nerve with the surface of their muscles. The same effect will be produced if the nerve of the frog's leg be placed on the muscles of a warm-blooded animal,—a rabbit, for instance,—care being taken to remove any thick aponeurosis which may cover the latter.

If an insulating substance be placed between the muscles of the thigh and the nerve of the leg, no action will take place. The same effect is observed when gold-leaf is interposed; but if the gold-leaf be torn, to however slight a degree, the leg will be thrown into contraction.

The electricity developed during the contraction of the muscles, stimulates the nerve which is laid upon them; the interposition of a non-conducting substance prevents the electric discharge from reaching the nerve; and gold-leaf, being a better conductor than nerve, carries the electricity along it, passing by the nerve.

4. The study of the effects of electricity applied in various ways upon nerves, has led to some highly interesting and curious results.

Nobili ascertained that, in passing an electric current through the lumbar nerves of a frog, contractions occurred under different circumstances, according to the state of vitality of the nerves. He divided the vitality of the nerve into five periods, during each of which different phenomena were produced by the passage of the current. In the first period, the *direct* current, or that directed from the brain to the nerves, caused contractions in the muscles on closing the circuit; the *inverse* current, or that from the nerves to the brain, on opening it. In the second period, the *direct* current causes contractions on closing the circuit, and slight ones on opening it; the *inverse* current causes contractions only on opening the circuit. In the third period, contractions occur only on closing the *direct* current and opening the *inverse*. In the fourth period, contractions occur only on closing the *direct* current; and in the fifth, the nerve ceases to be influenced by the electrical stimulus. Marianini, who subsequently studied this subject, affirms that contractions take place only under two circumstances, namely, from the closure of the *direct* current, or from opening the *inverse;* and that a sensation is caused by the *direct* current on opening, but by the *inverse* on closing.

Matteucci repeated these observations on the sciatic nerves of the rabbit, devoting one nerve to the direct, the other to the inverse, current. On closing the *direct* current, contractions were produced in the muscles of the limbs and back, with marked signs of pain; the same phenomena result from closing the *inverse* current, and from opening both. The signs of pain were greatest at the closure of the *inverse* current, and the contractions were most at the closure of the *direct* current. The commencement and the interruption of an electric current of a certain intensity, acting upon a certain portion of the nervous system, are followed by the same phenomena, whatever be the direction of this current in the nerve. After some time, which is shorter as the current is more intense, the phenomena take place in a different manner. Upon interrupting the direct current, the contractions of the muscles of the limbs are feeble, but there are signs of pain, and the muscles of the back are contracted; but, when the direct current is closed, the effects are limited to contractions of the posterior limbs. When the inverse current is used, contractions of the muscles of the back and signs of pain occur on closing it, while the contractions of the limbs are slight; but, on the interruption of it, contractions of the limbs alone take place.

The following tabular view will exhibit these latter results more clearly.

Direct current . .	closing . .	contractions in muscles of posterior limbs.
	opening . .	marked signs of pain, and contraction of muscles of the back. feeble contractions of posterior limbs.
Inverse current . .	closing . .	signs of pain, contractions of muscles of back, and feeble ones of the posterior limbs.
	opening . .	contractions of the posterior limbs.

So that, after the lapse of a little time, the phenomena produced by closing the inverse current, becomes precisely the same as those on opening the direct, and *vice versâ.*

The contractions of the muscles of the back, which are supplied from nerves which come off above the point of excitation, are due to the irritation of the nervous centre, affected through sensitive nerves; for these contractions cannot be produced if the portion of the cord from which the nerves arise have been removed.

After the nerve has been exhausted, so as to yield the phenomena of the second period, as shewn in the table, it may be excited to act as at first, either by increasing the intensity of the current, or by exciting points of the nerve nearer its peripheral extremities.

A simple experiment illustrates the different effects of the direct and inverse current in a very striking manner. The limbs of a frog are prepared according to the ordinary method of Galvani. If a current be passed from one side to the other through the lumbar nerves, it is plain that it will be direct in the nerves of one side, and inverse in those of the other side. During the first period, there are contractions both on completing and interrupting the circuit; but in the second period, one limb contracts on opening, the other on closing, so that the limbs are made to kick alternately, that which is traversed by the direct current on closing, and that by the inverse current on opening.

It is impossible to observe these curious phenomena, whether of the muscular current, or of the effects of electricity on nerves, without perceiving how utterly inexplicable they are by the electrical theory of nervous power, or, indeed, how much opposed they are to such a view. They serve, in the most remarkable manner, to confirm the views which we have advocated in a former chapter, which regard the nervous power as a polar force developed by molecular changes in nerves excited by various stimuli, of which, next to the mental, that of electricity is the most powerful.

We have already (p. 244) given the general results of Professor Matteucci's very interesting series of experiments on the torpedo. We shall content ourselves, now, with remarking that he has succeeded in illustrating very strikingly the marked analogy between the actions of the electrical organ and those of muscle, and the relation which each bears to the nervous system. Both are organised to act in a particular way; the one to develop electricity without any visible change in itself; the other to contract, with a demonstrable evolution of both heat and electricity. Both will manifest their peculiar phenomena by direct irritation, or by indirect irritation through the nerves. Both are brought under the control of the will by the nerves; the section of which paralyses the influence of the will over both, but does not destroy the peculiar power of either. In the electrical fish, irritation of the electrical lobe of the brain is capable of exciting a discharge of the organ; just as irritation of a segment of the spinal cord causes contraction of the muscles supplied by it. A current of electricity transmitted through the electrical organ or its nerves, causes discharge; and a similar current sent through a muscle or its nerves, causes it to contract. All the circumstances which modify the nutrition of muscle, will similarly affect that of the electrical organ.*

* Traité des phénomènes électro-physiologiques des animaux, par C. Matteucci; suivi d'études anatomiques sur le système nerveux et sur l'organe électrique de la Torpille, par Paul Savi. Paris, 1844.

CHAPTER XII.

ON SYMPATHY AND SYMPATHETIC SENSATIONS AND MOTIONS.

It is popularly known that the act of yawning, performed by one individual in a company, is apt to induce in many of the others an irresistible tendency to the same act. In a similar manner, the excitement of certain emotions (mirth or sadness, laughter or tears) is apt to spread through an assemblage of persons with extraordinary rapidity. The power of eloquence, of music, or of spectacle, to produce such effects, is witnessed every day in places of public resort, whether for devotion, business, or amusement.

Many instances are known in which convulsions have been excited in persons not previously subject to them, by the sight of a patient in an epileptic fit. And peculiar nervous disorders, of a convulsive kind, have been found to affect nearly all the members of a community without the slightest evidence of their being contagious or infectious. An impression upon an organ of sense may produce effects very different in their nature to anything which could be anticipated; and these may be purely of a physical kind, or they may act primarily upon the mind. Thus certain odours will induce syncope in some people; and the smell of a savoury dish to a hungry person, or even the mention or the thought of a meal, will excite a flow of saliva. The emotion of pity excited by the sight of some object of compassion, or by a narrative of a mournful kind, will produce a copious flow of tears.

All such phenomena are said to result from Sympathy. When one yawns, immediately in consequence of another's yawning, the former evidently and truly sympathises with the latter; and the convulsions which are induced by the sight of another in a fit, are not less sympathetic. The individual in whom the convulsions are induced sympathises with the other. Such obvious instances of sympathy between different individuals led to the supposition of some such similar consent between different or even distant parts in the same person.

Motions or sensations caused in certain parts in consequence of a primary irritation of other and distant parts are of the sympathetic kind. These motions or sensations are produced in, as it were, an indirect or circuitous manner, or one different from that in which they are ordinarily excited.

Thus a stimulus to the olfactory membrane causes a peculiar affection of the sense of smell, and thus occasions that depression of the heart's action from which results a state of syncope. Or, another affection of the same sense causes a suddenly increased action of the salivary glands.

If we analyse any one of these examples of sympathetic actions, it will appear that three circumstances are to be noticed in the production of the phenomena: 1st, the primary exciting cause, which may be an object presented to the mind through one of the organs of sense, or causing an impression upon any sensitive nerve, and therefore upon some part of the centre of sensation; 2ndly, the part affected directly by this primary stimulus; and, 3rdly, the action or sensation resulting from the affection of this part.

Many other sensations or motions may be enumerated besides those above referred to, whether occurring in health or in disease; and we shall give examples of these before we discuss this subject further.

The examples of sympathetic *sensations* which may be adduced are chiefly of the morbid kind. Pain is felt at a certain part, in consequence of an irritation in another part distant from it, and apparently altogether unconnected with it. One of the most familiar of these is pain in the knee from disease of the hip-joint. So marked in some instances is the pain in the knee, and so much has it absorbed the patient's attention, that the real seat of the disease has been overlooked, and the remedies been applied exclusively to the knee. Pain in the right shoulder from disease of the liver is a sympathetic sensation of similar kind; and sometimes the hepatic irritation causes pain over a more extensive surface. Whytt mentions, that, in two cases of suppuration of the liver, he had seen the patients "affected with a numbness and debility of the right arm, thigh, and leg." The peculiar sensations felt in the teeth from a noise which grates upon the ears, is sympathetic of the irritation of the auditory nerve. Practitioners are well aware how many morbid sensations in parts remote from the intestinal canal may be cured by the removal of scybala or other accumulations from it. Painful affections of the nerves of the face, and of other parts, are often due to a cause of this kind. The irritation of a stone in the bladder gives rise to pains in the thighs, or to itching at the end of the penis; and uterine irritation, whether from disease or from the enlargement of the uterus in connexion with the early stage of pregnancy, causes similar pains in the nerves of the thighs.

Headache and defective vision are frequently produced by disordered stomach. A draught of very cold water, or ice, taken quickly into the stomach, may occasion acute pain in the course of either frontal nerve. This same nerve on one side is frequently the seat of pain after the imprudent use of acid wines or other fermented liquors.

Movements, excited by the operation of a stimulus applied at a distance, form a large proportion of the instances of sympathetic phenomena. All the ordinary physical nervous actions in which motions are excited by stimulating a sentient surface, may be regarded as examples of sympathetic actions.* The contraction of the iris upon the application of the stimulus of light to the retina, or of the pharyngeal muscles by stimulating the mucous membrane of the fauces, are instances in point, where the stimulus acts indirectly upon the contracting fibre. Nothing is more sure than that in these instances the change wrought by the stimulus in certain sentient nerves travels by a circuitous route through a nervous centre to the muscles which are called into action. Akin to these actions are the forcible respiratory movements which may be excited by irritation of the tracheal membrane, as coughing; or sneezing, by stimulating the nasal membrane; or vomiting, by irritating the fauces. Spasmodic affections are often instances of morbid actions in sympathy with intestinal irritation, or the irritation of teething in children. Partial or general convulsions are very frequently due to either or both these causes. We have known the most violent opisthotonos coexisting for a considerable time with the presence of lumbrici in the intestine; but ceasing immediately on the removal of the worms. Vomiting is commonly sympathetic of diseased kidney, or of the passage of a calculus along the ureter; or it may be induced by the introduction of a catheter into the urethra. Irritation of the intestines, as in cholera, causes cramps of the most violent kind in the lower extremities and abdominal muscles. The contractions of the abdominal muscles in parturition, although materially aided by the will, are in consent with the expulsive efforts of the uterus.

* It has been remarked, that the term "sympathetic *actions*" involves a contradiction. But it may be observed, that the contraction of the muscles, on which the action depends, is only the natural mode in which that class of vital organs can manifest their consent with certain states of nervous centres, or of sensitive nerves. The action is the result of the state which the muscle assumes in sympathy with the stimulated nerve. The contradiction is therefore apparent not real.

The consentaneous action of symmetrical parts is no doubt due to a similar cause to that by which most of the sympathetic actions are excited, and more especially in those parts where symmetry of action is constant, although liable to be interrupted by the influence of the will.

A distinct class of sympathetic actions consists of those in which certain parts enlarge or become developed simultaneously with, and to a certain extent as an effect of, the increase of others. The penis, the beard, the vocal organs, experience a marked increase of development at the adult period of life simultaneously with the enlargment of the testes; and it may be added, in effect of their increase, because the early removal of these organs prevents the growth of the others. And so likewise as the ovaria are developed, the uterus, the vulva, the mammæ, increase in size; the ovarian and uterine irritation which accompanies the menstrual flux causes enlargement of the breasts, which subsides as soon as that period has gone by.

The various examples enumerated in the preceding paragraphs may be classed under three heads: first, sympathies between different individuals; secondly, those which affect the mind, and, through it, the body; and, thirdly, those which are strictly organic, and therefore physical.

Of the first class of sympathies we can offer no physical explanation. Whether the nervous system of one individual can directly affect that of another, or whether the effect is produced on the imagination, and afterwards on the nervous system, are questions still *sub judice.* The serpent fascinates his prey, apparently by the power of his eyes, and it is well known that one man can exert a marked control over another by a mere look; and in the same way men can control other animals, even the fiercest carnivora, by a firm and decided glance of the eyes. It is no explanation of sympathetic phenomena of this kind to ascribe them to the effect of a tendency to imitation. Imitation is voluntary; these actions are involuntary, or take place even in despite of the will.*

In the second class of sympathetic phenomena, an affection of the mind is a necessary link. But why that affection of the mind should produce its peculiar effect is a question of difficult solution. Why should the perception of certain odours produce in one case increased action of the salivary glands, and in the other case cause syncope? The only reply which can be made to this question is, that in these instances the impression on the sensorium causes a change there analogous to that which an original affection of the mind of similar

* Bostock's Physiology, vol. iii. p. 227.

kind would produce, and therefore gives rise to effects of the same nature as those resulting from that mental change. Thus the smell of savoury food excites in the mind the idea of food, which in a hungry man would, if it occurred spontaneously, occasion a flow of saliva. And the odour which occasions syncope, creates in the mind an emotion of disgust, which, if it arose independently of the physical impression, would affect the heart through the centre of emotion. It is plain, however, that that portion of the nervous centre which is affected in such cases, must have a direct influence upon the parts in which the sympathetic phenomena appear; and this through commissural fibres, or the continuity of its gray matter with that of the centre from which its nerves immediately spring; thus, in the instances referred to, the centre of sensation, which is first affected, is, through the medulla oblongata, connected with the salivary glands by the fifth nerve, and with the heart by the vagus.

We derive an explanation of the third class of sympathetic phenomena from the known laws of sensitive and motor nerves. It is known that stimulation of a sensitive nerve at its origin, or in any part of its course, will give rise to a sensation which will be referred to the peripheral extremity of the stimulated fibres; and that a stimulus applied to a motor nerve causes a change in it which spreads peripherad from the point stimulated, and therefore affects the muscular parts with which it is connected. It is known, also, that a sentient nerve may excite a motor or sensitive nerve which is implanted near to it in the nervous centre—doubtless through the change which it produces in that centre; nor can it be doubted that a sensitive nerve may receive such a powerful stimulus as to exalt the polar force of a large portion of the nervous centre in the neighbourhood of its insertion, and thus to excite a similar change in all the nerves, whether motor or sensitive, which are connected with it. Thus, according to the intensity of the original stimulus, there will be a radiation of nervous force from the centre, either in one or two motor or sensitive nerves, or in several such; and the number and variety of the sympathetic phenomena will thus depend on the intensity and extent of the change in the nervous centre excited by the primary stimulus.

To explain, then, the phenomena of sensation and motion under consideration, we must determine the individual nerves affected in each instance, and ascertain what connexions they have with each other. We learn from anatomical investigation, that, although nerves anastomose with each other in their distribution, this anastomosis is by no means of that kind which would justify the supposition that an irritation could be communicated from one to the other in their course. The nerve-fibres only lie in juxtaposition, but do not communicate; and there is an evident provision in the tubular membrane and white substance of Schwann for the insulation of the central axis, which is probably the effective substance in the nervous action. We must seek, therefore, in the nervous centres for such a communication between these nerves as may explain the excitability of one by the other. In the present state of our knowledge, we can do no more than state it as in the highest degree probable that nerves implanted in the centre immediately contiguous to each other can exert an influence upon the vesicular matter of the centre, and upon each other.

But there are certain facts which demonstrate, beyond all doubt, that, in such actions as we refer to, the integrity of the centre forms a necessary condition. First, in many of the instances, it is plain that there can be no connexion between the affected nerves elsewhere than in the centre; for they are so distinct from each other, that there is not even that apparent connexion which results from the anastomosis of a fasciculus of fibres of the one with a portion of the other. Secondly, the removal of the portion of the nervous centre with which any one of the nerves concerned in the sympathetic action is connected, will prevent the development of the phenomenon, although the nerves themselves remain uninjured in their peripheral distribution, or in their connexion with each other. Thirdly, if there were any peripheral communication between nerves, it would be most likely to take place in the plexuses. Experiments, however, upon the nerves which lead to these, shew that each nerve-tube, in its passage through them, retains its isolation as distinctly as in any other part of its course. The three nerves which supply the lower extremity in the frog, says Müller, form a plexus from which two nervous trunks issue: if one of these latter be divided and isolated from all its connexions with muscles, and the portion of it connected with the plexus irritated, the impression will be transmitted in the centripetal direction by the sensitive fibres of the nerve; but the motor fibres of the other nerve arising from the plexus are not affected, and excite no contractions in the muscles to which they are distributed.*

In applying these principles to the explanation of the instances which we have quoted, we shall find it difficult to determine the central connexion in some, although in others such a connexion is highly probable. It remains, therefore, for future anatomical research to ascertain what that connexion is which enables one nerve

* Baly's Müller, vol. i. p. 756.

to sympathise with another. In the instance of pain in the shoulder in sympathy with irritation of the liver, the hepatic irritation excites a change in some sensitive nerves, which is propagated to the centre, and there affects some of the sentient fibres distributed in the region of the shoulder. The phrenic and the external thoracic nerves are both or either of them, but more especially the former, favourably situated to constitute the excitant of such a sympathetic sensation. The phrenic nerve of the right side is largely distributed upon the peritoneal surface of the diaphragm, and upon the inferior vena cava, and forms many connexions with the hepatic plexus in the substance of the liver. It may therefore readily participate in any irritation of that organ. Now the phrenic nerve is implanted in the spinal cord on a level with the third or fourth cervical nerves; and the nerves of the shoulder form their connexion with this central organ about the same level. The origins of these nerves are sufficiently contiguous to each other to warrant the belief that an irritated state of one may be propagated to the other through the vesicular matter of the centre. But it may be inquired why the irritation is limited to the sensitive nerves of the shoulder; and why movements are not excited by the stimulation of the motor fibres of the phrenic itself, or of other nerves? The limitation of the irritation to one or two nerves depends on the degree of the stimulus, and the absence of movements is due to the disposition of the phrenic on the surface being unfavourable for the excitation of motions by irritation of its peripheral branches (see page 335). And the experiment cited from Müller, in the last paragraph, shews that simple irritation of the *trunk* of a compound nerve in connexion with the centre is not sufficient to produce motion; which requires probably either a more prolonged and violent irritation of the nerve, or a polar state of the centre in which it is implanted.

Some of the instances of sympathetic sensations, referred to above, do not admit of an explanation so obvious. The pain over the brow from ice or cold water in the stomach may be referred to irritation of the gastric branches of the vagus, communicated in the medulla oblongata to the fifth; but why the irritation should be limited to the ophthalmic division of the fifth cannot be accounted for in the present state of our knowledge.

In those sympathetic movements which are of ordinary and normal occurrence, two provisions seem to be secured, namely, a certain peripheral organization of the excitor nerve, and a certain central relation between it and the motor nerve. But in those which are of a morbid kind, it is necessary to suppose the existence of a more or less exalted polarity of the centre in order to explain the phenomena fully. This polar state will continue in many instances even after the primary peripheral irritation has been removed, as in tetanus, or in the convulsions from intestinal irritation; and we learn from this fact the importance in practice of attending to the state of the nervous centre as well as to the removal of the irritating cause.

There are other sympathetic phenomena, of the physical kind, in which, however, the nervous system does not appear to take a prominent part. Such are the changes which occur in different and distant organs in connexion with a particular period of life, or the development of a particular function. Among these are the phenomena of puberty in both sexes; the enlargement of the mammæ in pregnancy. Whatever part the nervous system may take in such changes, it is impossible to account for them by reference to that system only; they must rather be regarded as phenomena of nutrition occurring in harmony with the laws of growth, and therefore affecting the vital fluid more particularly than any part of the system of solid parts.

Continuity of texture disposes, as is well known, to the extension of a diseased state originating at some one point. So also does *contiguity.* Phlegmonous inflammation of the areolar tissue, and erysipelas in the skin, spread with great rapidity. Inflammation arising in one of the opposed surfaces of a serous membrane readily attacks the other. These effects have been vaguely assigned to sympathy (the *continuous* and *contiguous* sympathy of Hunter). But it cannot be supposed that the nervous system takes part in the production of such phenomena, which ought rather to be ascribed, in the one case, to the continuity of blood-vessels,—and, in the other, to contamination either by effused fluids or by morbid blood.

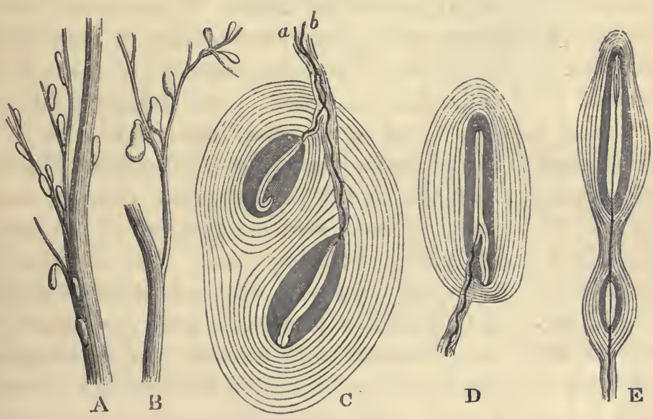
On the subjects referred to in this chapter, consult Whytt on the Sympathy of the Nerves, an admirable exposition of the phenomena, obscured, however, by his erroneous views respecting the all-pervading influence of the mind upon vital phenomena;—Hunter on the blood, etc.;—Alison on the Physiological Principle of Sympathy, Edinb. Med. Chir. Trans., vol. ii.;—Müller's Physiology.

CHAPTER XIII.

OF THE PACINIAN CORPUSCLES OF THE NERVES.

We propose to give in this chapter an account of certain very remarkable structures, appended to the nerves, to which attention has only very recently been drawn in this country.* These are the Pacinian corpuscles, so named by Henle and Kölliker† from their discoverer, Pacini.‡ In the human subject they are found in great numbers, in connexion with the nerves of the hand and foot, the nerves, as it may be presumed, of touch; but they also exist sparingly on other spinal nerves, and on the plexuses of the sympathe-

Fig. 74.



A. Nerve from the finger, natural size shewing the Pacinian corpuscles.
B. Ditto, magnified 2 diam.; shewing their different size and shape.
C. Unusual form, from the mesentery of the cat; shewing two included in a common envelope: —*a. b.* are the two nerve-tubes belonging to them.
D. Another, from the same; shewing an offset from the central cavity, containing a branch of the pale nerve.
E. Rare form, from the mesentery of the cat (reduced from Henle and Kölliker); shewing two corpuscles placed in succession on a single stalk, and furnished with the same nerve-tube, which resumes its white substance in the interval between them.

* Brit. and For. Med. Rev., Jan. 1845.

† Ueber die Pacinischen Körperchen an den Nerven des Menschen und der Säugethiere. Zurich, 1844.

‡ Pacini first noticed them in 1830, and subsequently in 1835; and in 1840 gave an account of them (Nuovi organi scoperti nel corpo umano dal

tic, though never on the nerves of motion. In the mesentery of most cats they are very readily seen by the naked eye (usually in considerable numbers), as pellucid, oval grains, rather smaller than hemp-seeds, and they are here very favourably situated for examination. Fig. 74, A, B, will give a correct idea of their relation to the nerves in the palm and sole. They are especially numerous on the smaller twigs, to which they are generally placed parallel, though frequently at an acute, and sometimes at an obtuse angle. They are more or less oval, often elongated and bent; sufficiently tough to resist moderate pressure, and nearly transparent, with a whitish line transversing their axis. They lie imbedded in the areolar tissue, and adhere to it by their outer surface. They always present a *proximal end*, attached to the nerve by a *stalk* of fibrous tissue, prolonged from the neurilemma and occasionally $\frac{1}{10}$ of an inch long; and a *distal end*, lying free in the areolar tissue. The corpuscles in the human subject have an average length of from $\frac{1}{20}$ to $\frac{1}{10}$ of an inch.

A minute examination of these singular bodies discloses an internal structure of a highly interesting kind. They consist, first, of a series of membranous capsules, from thirty to sixty or more in number, enclosed one within the other; and, secondly, of a single nervous fibre, of the tubular kind, enclosed in the stalk, and advancing to the central capsule, which it traverses from end to end.

By reference to the accompanying figure (75), which exhibits the general structure, the ten or fifteen innermost capsules may be observed to be in contact with one another, while the rest are separated by a clear space containing fluid. This is almost constantly observed, unless the specimen has been allowed to imbibe water sufficient to detach the inner capsules from each other; and hence these have been distinguished from the rest as the *system of internal capsules*. The intercapsular spaces between the others vary in width, especially under pressure, and sometimes we have seen some of the outer capsules in close contact. The capsules are here and there united by connecting bands of similar structure, passing, transversely or obliquely across the spaces; the spaces do not com-

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Dott. Filippo Pacini. Pistoja, 1840), which has been rendered much more accurate and complete in its details by Henle and Kölliker. Coming to the investigation of these corpuscles with the knowledge of what these eminent anatomists had accomplished, we have confirmed their results by numerous observations, from which the account about to be given has been principally taken. A. G. Andral, Camus, and Lacroix had announced their existence at a *concours* in Paris, in 1833, but do not appear to have apprehended their real nature.

municate: if some of the outer capsules are punctured, their fluid escapes; but those within remain distended. A single puncture down to the inner series of capsules causes all the fluid to escape, and the whole to collapse; and again, the capsules may be often peeled off in succession, shewing their union to be but slight. In fact, except by the few bands already mentioned, they are united only along the stalk, and for a variable extent at the opposite end. The stalk seems to be inserted into a kind of conical tube, which penetrates all the capsules in succession, but has its proper wall, so as not to communicate with the intercapsular spaces. This wall connects the capsules, and the fibrous tissue of the stalk is gradually united with its inner surface as far as the central capsule, where it terminates. There is generally a strong union between a variable number of the capsules, as we trace them from the opposite end of the central capsule towards the surface (fig. 76, B, *o*); this was called by Pacini *the intercapsular ligament.* We do not, with Henle and Kölliker, deny its existence, but have seldom seen it reach the surface of the corpuscle.

Fig. 75.

Pacinian corpuscle, from the mesentery of a cat; intended to shew the general construction of these bodies. The stalk and body, the outer and the inner system of capsules with the central cavity are seen. *a.* Arterial twig, ending in capillaries, which form loops in some of the intercapsular spaces, and one penetrates to the central capsule. *b.* The fibrous tissue of the stalk, prolonged from the neurilemma. *n.* Nerve-tube advancing to the central capsule, there losing its white substance, and stretching along the axis to the opposite end, where it is fixed by a tubercular enlargement,

The wall of the capsules of the internal system often appears to consist of two laminæ. The inner of these contains, at intervals, flattish, oval nuclei projecting inwards (fig. 76, A, *d*). The outer is sometimes seen, as if in section, by a series of dots, representing transverse or circular fibres. The capsules always exhibit a decided transverse fibrillation, which in a great measure disappears on the addition of acetic acid, shewing the almost complete absence of the yellow fibrous tissue. The outermost capsule of all, however, is invested with a network of this, as well as of the white fibrous element of the areolar tissue. The internal capsules do not shew the double wall, but they contain nuclei.

The capsules seem to be over-distended by their fluid, so as to be naturally kept tense. If allowed to dry, they do not fill again on being moistened.

The fluid of the intercapsular spaces is so abundant as to constitute far the largest portion of the bulk of the entire corpuscle, and by its clearness imparts the peculiar pellucid lustre so characteristic of these bodies. It is supposed to resemble the serum of the blood.

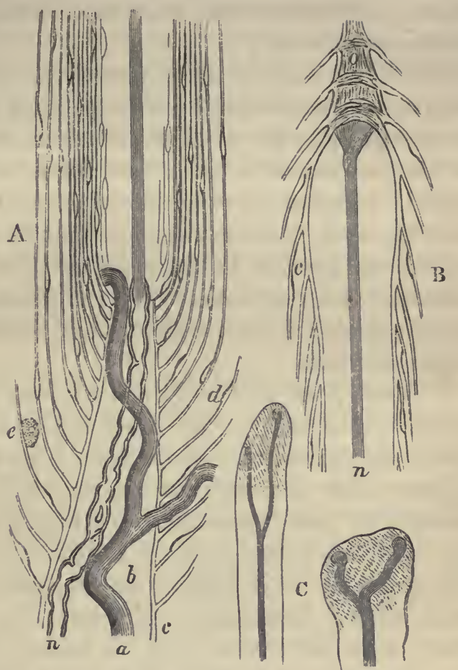
There are generally a few capillary blood-vessels ranging over the surface of the corpuscles; but the capsules are chiefly supplied by a minute artery that enters in the fibrous tissue of the stalk, sends off a few capillaries which perforate the tubular canal, and form each a short loop in the intercapsular space (fig. 75): one capillary vessel usually reaches the central capsule (fig. 76, A), and sometimes, though rarely, may be traced some way along its wall. In the larger corpuscles of the palm and sole, the capillaries penetrate to the distal part of some of the intercapsular spaces, and may there form a kind of bunch before returning. If a quite recent specimen be examined, under a high magnifying power, the blood-globules are often visible in the capillaries, and, by their swelling on the addition of water, may be sometimes hurried into a sort of circulation. When this happens, the course of the blood in the corpuscle is displayed with singular beauty.

We have said that the stalk of every corpuscle contains a single nerve-tube. When two corpuscles are seated on a common stalk, two nerve-tubes are included, one of which belongs to each (fig. 74, c).

The nerve-tube is proportioned in size to that of the corpuscle, that is, to the number of capsules composing it. Even when smallest, it is conspicuous enough, if the specimen be recent; for it is invariably furnished with the white substance of Schwann, and displays the double contour. When largest, it equals any found in the body. It is very liable to present varicosities, and its course in the stalk is more or less undulating.

On entering the innermost capsule, the nerve-tube suddenly loses its envelope of white substance and becomes pale; the axis-cylinder alone remaining, perhaps still invested by the tubular membrane (see p. 208). Thus reduced in size and rendered pale, the nerve stretches like an arrow along the very centre of the capsular cavity to the opposite end, where it swells into a knob, or button, which fixes itself to the inner surface of the capsule. In this swelling nothing can be detected beyond the pale, faintly fibrous character of the axis-cylinder. No nucleus, like that of the caudate nerve-vesicles, can be seen. Sometimes the axis-cylinder divides near its termination into two or even into three branches, each of which terminates by an adherent swollen extremity. Sometimes this division occurs near the proximal end of the central capsule, and one of the branches passes in a retrograde course into a subordinate offset from the central cavity, and there terminates (fig. 74, D). In the midst of these varieties one thing is constant, viz., the remarkable accuracy with which the pale nerve pursues its path in the axis of the cavity, everywhere equidistant from the walls. This is most apparent when the cavity is bent upon itself, and when it might be imagined that the nerve would incline from the centre towards the concavity of the bend; but it keeps a central course there as well as elsewhere. This, perhaps, may depend on the nature of the contents of the central cavity, immediately enveloping the pale nerve. Near the wall of the cavity an appearance of soft, delicate, longitudinal fibres, with elongated nuclei, is often visible (fig. 76, A); and, although the space immediately surrounding the nerve is quite transparent, we are disposed to consider the

Fig. 76.



A. Termination of the stalk, and commencement of the central cavity. *n*. Nerve-tube advancing to the central capsule, and there suddenly losing its white substance and becoming pale. *a*. Artery ending in capillaries; one of which enters an interscapular space, the other advances with the nerve into the inner capsule. *b*. Conical tubes which receive the stalk: the fibrous tissue of the stalk is not represented. *c*. Wall of this tube, continuous with the successive capsules, here seen in section. *d*. Corpuscle of the capsular wall. *e*. More spherical granular corpuscle, of which a few only exist.

B. Distal end of the central cavity. *n*. Pale nerve advancing along the axis to be fixed by a swollen part at the further end. *c*. Wall of the central cavity, receiving the insertion of some of the neighbouring capsules, here a little separated from each other by water. *o*. Intercapsular ligament of Pacini, continued a little way towards the surface.

C. Two varieties of bifid extremity of nerve, attached to the distal extremity of the central cavity.—All magnified 320 diam.

substance occupying it sufficiently solid to keep the nerve in its place. It does not seem to be mere fluid, like that distending the intercapsular spaces.

Henle and Kölliker have remarked, that, where two corpuscles are seated in succession on a single stalk (fig. 74, E), the pale axis-cylinder regains its envelope of white substance from its point of leaving the central cavity of the first, to its entering that of the second; and that in some cases, where the central cavity is bent suddenly upon itself, so that it cannot be fairly surrounded by capsules at the bend, it is there provided for a little way with white substance. A very delicate layer of the same substance, just thick enough to give a dark edge, occurs occasionally along the course of the pale fibre.

We have gone thus minutely into the structure of the Pacinian corpuscles, because of the novel aspect in which they present the constituent parts of the nerve-tube, placed in the heart of a system of concentric membranous capsules with intervening fluid, and divested of that layer which we regard as an isolator and protector of the more potential central axis within. The object of this arrangement is quite unknown, and, in the present uncertain state of our knowledge respecting the nature of the nervous force, it seems almost idle to hazard guesses on the subject. The apparatus of lamellæ may either effect some change in the enclosed nerve, by which the nervous centres in connexion with it may be influenced as to their polarity; or, on the other hand, this apparatus may be the special instrument of some peculiar vital agency, which the nervous filament is designed simply to bring into communication with the nervous system. The latter view, to which we incline, would bring these organs under the same category with muscles, and the organs which develop light or electricity in certain of the lower animals. Pacini has already drawn a comparison, in point of structure between them and the electrical organs of the torpedo; and Henle and Kölliker favour this idea. The well-known prisms of the electrical organs, according to Savi,* consist of a congeries of very delicate transverse lamellæ, on which the nerve-tubes are distributed in a plexiform manner; and, if we may judge from his figure, this plexus is not resolvable into loops, but consists of true inosculations of the ultimate tubes, which also retain the white substance of Schwann: but further researches are greatly needed on this point. Wagner, with more probability, describes the

* Paul Savi, in Matteucci, loc. cit.

nerves to terminate on the lamellæ in the same looplike manner as in striped muscle.* These lamellæ are separated by fluid, and only adhere through the medium of the wall of the prism. If this be the true history of this structure, it appears to establish some general analogy between the electrical organs and the corpuscles; but how far this can be shewn to hold in essential characters, especially in the mode of termination of the nerves, and their arrangement with regard to the membranes and fluid, is still a matter of doubt. Meanwhile we deem it most prudent to forbear from speculating concerning the office of the Pacinian corpuscles.

Having thus far completed the physiological anatomy and physiology of nerves in general and nervous centres, we proceed next to the consideration of particular nerves; and we shall state here the order in which we find it convenient to examine them. The Encephalo-spinal nerves very conveniently arrange themselves into the three following classes:—I. The nerves of pure sense. II. The nerves of motion. III. The compound nerves. The first class includes some nerves, namely, the nerves of touch and taste, which are mixed up with those of the third class; but, as the consideration of these senses could not without great inconvenience be separated from the others, we prefer to consider these particular fibres along with the other nerves of pure sense, namely, the olfactory, the optic, and the auditory. As the peculiar function of those nerves depends on the peripheral organization, as well as on their central connexion, their physiological anatomy involves necessarily that of the organs of sense. We shall commence with the most simple, namely, Touch and Taste, and afterwards proceed to Smell, Vision, and Hearing.

The second class of nerves contains the third, fourth, sixth, portio dura of the seventh, and the ninth pairs of nerves according to Willis's arrangement, all of which are motor in function.

In the third class we place the fifth and eighth pair of nerves, and the spinal nerves.

Lastly, we shall examine the Sympathetic nerve.

* Comparative Anat., translated by Tulk.

CHAPTER XIV.

GENERAL REMARKS OF SENSATION.—OF THE SPECIAL SENSES.—OF THE SENSE OF TOUCH.—ANATOMY OF THE SKIN, AND ITS APPENDAGES.

Sensation is an affection of the mind occasioned by an impression made on certain parts of the nervous system, hence called sensitive. A state of the sensitive organs, and a corresponding perception by the mind, must concur to produce sensation: either condition may exist alone, but then the phenomenon is not a true sensation, in the acceptation here given to the word. Thus, light falling on the eye in sleep excites the whole visual sensitive apparatus, while the organ of perception is inactive: on the other hand, in dreams, vivid pictures of objects float before the mind, and are referred by it to the external organ, which may be all the while entirely quiescent.

The organs of sensation are those parts of the nervous system, with their dependencies, which, when stimulated, occasion in the mind a perception of the impression. Hence certain parts of the cerebro-spinal centre, as well as certain nerves and their peripheral expansions, are comprehended under this term. It is remarkable that the organ of the mind itself does not appear capable of thus undergoing sensory excitement. Little is known of the central parts of the organs of sensation, in consequence of their deep seat, and of their ill-defined limits. The peripheral parts are more conspicuously placed, and on several accounts are commonly styled, *par excellence,* the organs of sensation: they are specially adapted to receive in the most advantageous manner the impressions to which their excitability is adapted to respond. The intervening nerves are, more properly speaking, media of transmission.

Sensations excited by a stimulus originating in the body itself, especially if it act rather on the intermediate or central part of the sensitive apparatus than on the peripheral, are termed *subjective:* on the other hand, they are styled *objective* if the stimulus be derived from without.

Under the name of *common* or *general sensibility* may be included a variety of internal sensations, ministering for the most part to the organic functions and to the conservation of the body.

Most parts of the frame have their several feelings of comfort and pleasure, of discomfort and pain. In many of the more deeply seated organs no strong sensation is ever excited, except in the form of pain, as a warning of an unnatural condition. The internal sensations of warmth and chillness, of hunger, thirst, and their opposites, of nausea, of repletion of the alimentary and genito-urinary organs, and of the relief succeeding their evacuation, of the privation of air, etc., with the bodily feelings attending strongly excited passions and emotions, may be mentioned among the principal varieties of common sensation.

The *special* sensations are referrible to five leading forms, and are distinguished not less by their several modes or characters, than by the more special and elaborate construction of the peripheral parts of their respective organs, whereby these are adapted to receive the impressions of their appropriate stimuli. The special sensations excited through the instrumentality of the peripheral organs of *touch, taste*, *smell*, *vision,* and *hearing*, are primarily designed to inform the mind of the conditions of the external world; and it is for the most part only in a secondary manner, or through the mind, that they operate on the organic functions, or for the conservation of the body.

Almost all sensation is attended with the idea of locality, the mind referring the cause of the change it experiences to the peripheral part of the sensitive apparatus excited. Thus the ideas of distance, extent, and relative position, originate in the very construction of our bodies, and soon become applied to the material objects around us by the comparison of the impressions on our different organs, and their several parts, with one another. The abstract idea of space is a further conception of the mind.

OF TOUCH.

This is the simplest and most rudimentary of all the special senses, and may be considered as an exalted form of common sensation, from which it rises, by imperceptible gradations, to its state of highest development in some particular parts. It has its seat in the whole of the skin, and in certain mucous membranes, as that of the mouth, and is therefore the sense most generally diffused over the body. It is also that which exists most extensively in the animal kingdom; being, probably, never absent in any species. It is, besides, the earliest called into operation, and the least complicated in its impressions and mechanism. On these accounts it will be the first treated of.

The nerves of touch are the same, or at least are derived from the same part of the cerebro-spinal centre as those of common sensation. They are the posterior roots of the spinal nerves, and some fibres of the eighth and fifth encephalic nerves. The peripheral organ of touch to which they are distributed is a tissue everywhere diffused over the sentient surface, but which in most situations is elevated into papillæ more or less distinct from one another, and closely set, according to the tactile power. The nerves of touch are remarkable for the ganglia which are formed upon them on their emergence from the vertebral canal, and for the subsequent admixture with most of them of nerves of motion. In these respects they differ from those of the other special senses, except taste, which ranks next to touch in the ascending scale.

In accordance with our general plan, we shall commence with an anatomical description of the skin, which is the principal seat of touch; and it will be convenient to include with it an account of the various glands and appendages found in connexion with this organ, whether they have any relation to the sense in question or not. We must premise, however, that this external integument is a part only of a great physiological system, which comprehends also the mucous membranes, and the true or secreting glands; all of which, taken together, and reduced to their most simple expression, are a continuous membrane, more or less involuted, more or less modified in the elementary tissues which compose it or are in connexion with it, and within which all the rest of the animal is contained. This expanse consists of two elements; a *basement tissue* composed of simple membrane, uninterrupted, homogeneous, and transparent, covered by an *epithelium*, or pavement, of nucleated particles. Underneath the basement membrane, vessels, nerves and areolar tissue are placed (p. 47).

The sense of touch exists only in those regions of this great system which are exposed to the contact of foreign bodies, and where it is essential to the comfort or preservation of the animal that the presence and qualities of external objects should be perceived. These regions, however, demand a greater protection, for the same reason; and hence it happens that the development of this sense is found to be generally accompanied with the most remarkable increase and transformation of the epithelial element, and of the areolar tissue lying under the basement membrane. In the skin the thick and hard epithelium is termed *cuticle* or *epidermis*, and the dense and altered areolar tissue constitutes by far the largest proportion of the *cutis derma* or *cutis vera*.

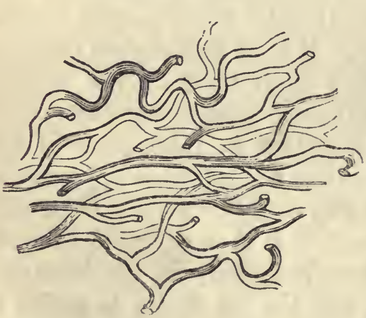
The *external surface* of the skin, formed by the cuticle, (which everywhere adapts itself to the form of the surface on which it rests), is marked by furrows of various kinds. Some of these (furrows of motion) occupy the neighbourhood of joints, especially on the side of flexion, and are generally transverse, facilitating the formation and determining the position of the folds that result from the movements of one segment of a limb on another. Others correspond to the insertion of cutaneous muscles; for example, many of those which give force and character to the features; and these are much modified by the quantity of subjacent fat. The elevator muscle of the lower lip thus causes the "double chin." Furrows of another kind are seen in aged and emaciated persons, and after the subsidence of any great distension of the integument, such as that occasioned by anasarca or pregnancy. But, besides these coarser lines, almost every part of the skin is grooved by numberless very minute furrows, which in the more highly developed regions run in nearly parallel curved lines, and elsewhere assume a stellated arrangement, or form a close interlacement of no regular figure. These lines are important, as they depend upon peculiarities in the texture of the skin, having particular relation to the sense of touch: they may be best studied on the palmar aspect of the hand and fingers, and on the sole of the foot. The outer surface of the skin likewise presents innumerable pores, the orifices of the sebaceous follicles and sudoriferous ducts; and the various modifications of the epidermis, termed "appendages of the skin," as hairs, nails, etc., all project on the same aspect.

The *deep surface* of the skin is formed by the cutis, or cutis vera, and is attached to the parts which it invests by an extension of the areolar tissue, of which it is itself principally composed, as well as by vessels, nerves, and sometimes muscular fibres, passing into its substance from the subjacent region. It is on this surface that the sweat-glands rest; they are imbedded in it more or less deeply, according to their size, and the length of their excreting ducts; and together with the fatty pellets, so abundant in most parts of the subcutaneous fascia, occasion that areolar or cribriform appearance, which is seen on this aspect of a cleanly dissected portion of integument. In preparing such a specimen, it is at once made evident, however great the difference may seem to be between the dense and closely woven texture of the cutis and the lax fascia to which it owes its mobility on subjacent organs, that these tissues blend insensibly together, and are not separated from one another by any abrupt limit. Their ultimate texture is indeed essentially the same. Hence the boundary we assign to the skin in this direction is in some measure artificial. Its precise nature will be seen by considering the

Intimate Structure of the Cutis.—The white and yellow fibrous elements of the areolar tissue are both much modified, to constitute the framework of this layer; and in different parts of the skin, as may be expected, they exist in different proportions, and in some variety of arrangement. These varieties are not yet made out in all their particulars; but we believe we may state in general, that, where great extensibility, with elasticity, is required, the elastic element predominates (as in the skin of the axilla); and that where, on the contrary, resistance is demanded, the cutis is chiefly composed of a dense interweaving of the inelastic white element (as in the sole of the foot). But in all situations the meshes are very close, and the quantity of the mixed fibrous tissues very great, as compared with almost any other part of the body (pp. 77—9).

The fibres of the *yellow element* take a generally horizontal course, and lie in multiplied series over one another, branching at very frequent intervals, to join those above, below, and on either side. The resulting meshes are open on all sides, but are most flattened in a direction parallel with the general surface. They are more or less lozenge-shaped, and vary in size not only with the region of the skin in which they are examined, but according to their immediate relations with the sudorific ducts, and of other cutaneous appendages which traverse them. This element of the cutis can be easily studied on thin vertical slices, moistened with acetic acid, which acts on other parts, leaving it entire, and, as it were, isolated. (Fig. 77).

Fig. 77.



Yellow fibrous element of the cutis of the axilla.—Magnified 320 diameters.

The thick and abundant fibres of the *white element* twine in great profusion among the interstices just described, but what their precise attachments are it is difficult to determine. They accompany all the larger vessels and nerves, and invest the several small glands with a loose capsule.

The *gelatine,* which may be obtained in considerable quantity from the skin, is derived from this latter part of the cutis, and it is probably this element also which is principally concerned in the changes the skin undergoes during the process of tanning. The varieties in the qualities of different skins for this purpose might be explained by a reference to these two varying elements of their fibrous framework. In the museum of King's College is a specimen of excellent leather tanned from the skin of Bishop, one of the murderers of the Italian boy who fell a victim to the infamous system of "Burking" many years since.

Some anatomists have thought that the contractility of the skin, manifested under the influence of cold, and even under certain emotions, is due to the existence of peculiar fibres; and Gerber has very recently figured what he considers to be such fibres. He describes them as begirting the hair-bulbs.

There is good reason for believing that these fibres, if they exist, do not essentially differ from those of unstriped muscle; for in the dartos we have found the latter intermingled with an abundant and lax areolar tissue: and the close resemblance between the contraction of the scrotal membrane and that of the skin has been generally recognised. In fact, the dartos seems to be nothing more than a modification of the dermoid and subdermoid tissue, of which the principal peculiarities are the excess of this form of muscle, the laxity of the meshes, and the absence of fat. It is probable, also, that the phenomenon of "erection" of the nipple is due to the contraction of similar fibres.*

The thickness and strength of the *cutis*, or *areolar framework of the skin*, differ greatly in different parts, according to the amount of resistance required against internal or external pressure. On the hinder surface of the body it is denser than in front, and on the outer than on the inner surfaces of the limbs. It is unusually thin over the flexures of the joints. It is particularly delicate in the eyelids, and proportionally so in some other situations, where great mobility is demanded. In regions which are most subject to external pressure, as the soles of the feet, it is firmly united by very dense laminæ to the subcutaneous fascia; and the intervals between these are provided with pellets of fat, forming a cushion, as an additional means of protection to the delicate organs it encloses and covers.

Among the lower animals, we may notice numberless examples of an analogous kind. One of the most striking is that of the great whales, which, being liable to enormous pressure on the surface of

* Cyclop. of Anat. and Phys. vol. iii. p. 518.

their bodies, from the medium in which they live, are provided with a cutis of extraordinary toughness and density, as well as with a growth of subcutaneous fat, called *blubber*, of prodigious thickness.

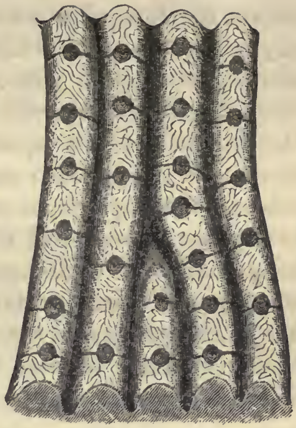
Fat occurs very generally in the subcutaneous areolar tissue, serving as a soft bed on which the skin may rest, and giving roundness and symmetry to the outline of the body.

It is on the exterior surface of the cutis that the *tactile papillæ* are developed; and it is here to be remarked that there is no necessary relation between the degree of their development, and of that either of the dermoid framework which supports, or the cuticle which covers them. It is true that in the palm and sole all these attain a large size, but, in the back, the tactile organ is well-nigh absent, though the cutis is dense; and in the tongue, on the contrary, this organ is highly developed; while the areolar framework is nothing more than a very thin expansion; and the investment of cuticle is so thin that the papillæ form separate projections from the surface. On the buccal surface of the lips and cheeks, too, the cuticle is comparatively thin.

In all parts of the cutaneous surface, as well as in some portions of the internal mucous tracts, *common sensation* exists, attended with a feeble discriminating power, which must be regarded as the lowest condition of the sense of *touch*; but the organ peculiarly fitted for receiving tactile impressions is concentrated in a very remarkable manner in certain portions of the integument, which in other respects, whether from the precise and varied movements they can perform, or from their peculiar position, are the best adapted to be inlets of this kind of sensation. The palmar surface of the hand and fingers, or the sole of the foot, may be selected for description, as presenting the most highly developed form of the organ of touch.

The integument in these regions is finely and regularly furrowed by grooves, separated from one another by corresponding ridges. The direction of these grooves and ridges is various; they run in sweeping curves, frequently branch to adapt themselves to the inequalities of the general surface, and differ somewhat in width and distinctness. These lines indicate the arrangement and development of the tactile organ below. Each ridge is produced by a single or double row of elongated conical processes, termed papillæ, projecting from the surface of the cutis into the epidermis. The grooves are occasioned by the epidermis sinking in to occupy the intervals between the rows af papillæ. The papillæ in each row are usually arranged in pairs, the intervals between which are indicated on the outer surface by corresponding minute and very shallow grooves, crossing the tops of the ridges more or less at right angles. Each pair of papillæ thus occupies a little division of the ridge. In the centre of each cross line, between the pairs of papillæ, is observed the orifice of a sweat-duct (shortly to be noticed), which often is so large as to destroy the linear character of the cross groove. In a square inch of the palm we may generally count rather more than forty rows of papillæ, and in each row rather more than sixty pairs of them.

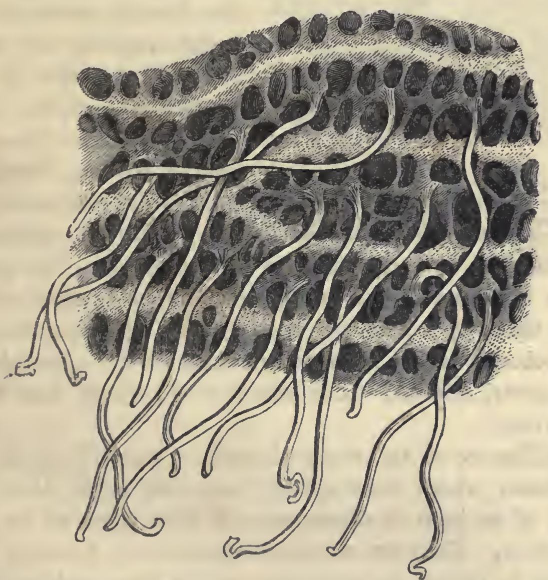
Fig. 78.



Surface of the skin of the palm, showing the ridges, furrows, cross grooves, and orifices of the sweat-ducts. The scaly texture of the cuticle is indicated by the irregular lines on the surface.—Magn. 20 diam.

In the natural state the papillæ are intimately united at all points of their surface to the epidermis which invests them. By a slight maceration this union may be so loosened that the two structures may be readily

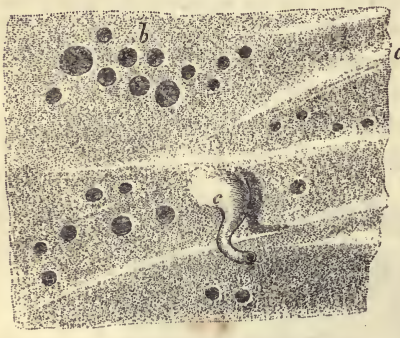
Fig. 79.



Under-surface of the cuticle, detached by maceration from the palm; showing the double rows of depressions in which the papillæ have been lodged, with the hard epithelium lining the sudoriferous ducts in their course through the cutis. Some of these are contorted at the end, where they have entered the sweat-gland—Magnified 30 diameters.

separated from one another. In gradually tearing off the epidermis, the foregoing account of the arrangement of the papillæ may be fully verified with the aid of a pocket lens. They are seen to form a close pile on the surface of the chorion, each one being lodged in a separate cavity in the deep surface of the cuticle. The papillæ are not equal in size, but frequently a small one is joined with a large one: and the clefts left between them, by the removal of the epidermis, are unequal likewise; those between the rows being deepest, and those between the individuals of a pair being commonly shallower than those between the pairs. This subordination corresponds (though not accurately in degree) with that of the grooves on the outer surface of the cuticle, where the shallow intervals between the individuals of a pair are not even visible at all, being lost by the thickness of the superimposed substance. Such is the exactness of the impression or mould of the papillary structure which the under-surface of the epidermis presents, that it furnishes an excellent test of the amount and complication of the former structure in different regions of the skin. This will be seen by comparing figs. 79 and 80; the latter of which, taken from the cuticle of the leg, represents the shallow depressions into which the few dwarf papillary elevations of the cutis in that part have been received. The gradations of size in the papillary structure can be everywhere admirably traced in this way; and will be found to correspond accurately with the account of the relative acuteness of the sense of touch in different parts, deduced from experiments, which will be subsequently given.

Fig. 80.



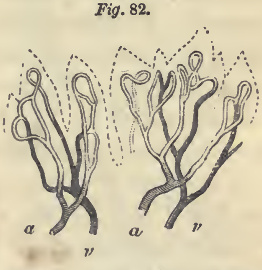
Under-surface of the cuticle, from the leg:—*a.* Small creases or furrows. *b.* Shallow depressions for the papillary structure. *c.* Epithelium of sudoriferous ducts, corresponding to those in fig. 79.—Magn. 30 diam.

The papillæ are of an average length in man of $\frac{1}{100}$ of an inch; at their base, where they spring from the cutis, they measure about $\frac{1}{250}$ of an inch in diameter, and they taper off to a slightly rounded point. They are semi-transparent and flexible; but sufficiently firm in texture to resist maceration long, and not readily to admit of being detached from the cutis. Viewed, when fresh, with a high microscopic power, their outline is definite and sharp, and there is good reason to suppose it formed of an unbroken expansion of the homogeneous basement membrane already spoken of. Within this it is difficult to distinguish any special tissue, except by artificial modes of preparation. A fibrous structure, however, is apparent, having a more or less vertical arrangement: and with the help of solution of potass, filaments of extreme delicacy, which seem to be of the elastic kind, are generally discoverable in it. Injection of the blood-vessels demonstrates the existence of a small arterial twig derived from the arterial plexus of the cutis, entering at the base, advancing up the interior of the papilla, and subdividing into two or more *capillary vessels*, according to the size of the particular organ. These, after forming small loops, reunite either at the base of the papilla, or in the subjacent texture, into small veins, which empty their blood into the venous plexus of the cutis. The capillaries of the smaller papillæ frequently join with those of the fat-vesicles that lie beneath. The vascularity of the papillæ is such, that their presence and relative size may be determined simply by the depth of the colour imparted to a portion of skin by a good injection of its vessels. The vascularity of the integument is, therefore, in general terms, proportioned to its perfection as an organ of touch.

Fig. 81.

Papillæ of the palm, the cuticle being detached.—Magnified 35 diameters.

Fig. 82.



Vessels of papillæ, from the heel: — *a.* Terminal arterial twig, *v.* Commencing vein. — Magnified 80 diameters.

Since the discovery of the papillæ as the sentient organs, the existence of *nerves* within them has usually been taken for granted, or they have been loosely styled expansions of the nerves; and to the general truth of such statements we may readily assent. But we have reason to doubt the accuracy of some recent writers, who have professed to give minute details of the mode of termination of the nervous tubules in the papillæ. The subject is difficult of investigation. According to Ernst Burdach* and others, the nerves are arranged in a plexiform manner under the skin of the frog, and loops are formed by the union of tubules from neighbouring branches. On examination we find this description correct as far as it goes, but that it does not carry us to the papillary structure. The plexus in question is situated underneath an expansion of fibres crossing each other at right angles, which is itself placed

* Beitrag zur Mikroskop. Anat. der Nerven: Königsb. 1837.

beneath the true skin, and separable from it; and we have observed single tubules from the plexus penetrating this expansion in their course to the skin. They have then been lost to view. We have hardly been more fortunate in discovering the true termination of the nerves in the nictitating membrane of the eye in the same animal, or in the papillary tissue so largely developed on the thumb at a certain season.

In our attempts to follow the nerves for any distance under the papillary structure in the higher animals, the fibrous tissues (and especially the elastic variety), forming the cutis, have been found so much to impede the view, that no satisfactory conclusion has been arrived at. In regard to their presence in the papillæ themselves, we can affirm that we have distinctly traced solitary tubules ascending among the other tissues of the papillæ about half-way to their summits, but then becoming lost to sight, either by simply ending, or else by losing the white substance of Schwann, which alone enables us to distinguish them in such situations from other textures. Thin vertical sections of perfectly fresh specimens are essential for this investigation, and the observer should try upon them the several effects of acetic acid and solution of potass. In thus describing the nerves of the papillæ from our own observations we do not deny the existence of true loop-like terminations as figured by so respectable an authority as Gerber,* but neither do we feel entitled to assent to it. We have in numerous instances failed to detect any nerves at all within the papillæ, when such were plainly visible at their base, and when, consequently, the chemical agent employed could scarcely have destroyed their characteristic structure, had they been present. We incline to the belief that the tubules either entirely or in a great measure lose the white substance when within the papillæ. We would, however, refer the reader to what will be found respecting the nerves of the papillæ of the tongue on the chapter on taste.

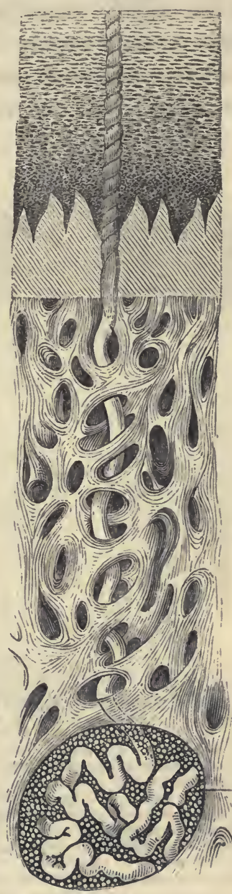
The essential tissue of the papillæ probably exists even where no projections large enough to be called papillæ are present. These portions of the skin are more scantily supplied with nerves; and it is probable from this circumstance, as well as from experiments afterwards to be detailed, that the individual nervous tubules are wider asunder, and occupy each a more extensive surface than in parts thickly set with papillæ.

The *cuticle*, or *epidermis* (fig. 83, *a*), like the cutis, varies greatly in its thickness. As its chief use is that of affording protection, it attains most density on parts most exposed to pressure and friction,

* General Anatomy, translated by Gulliver.

as the soles of the feet and the palms of the hands. In the same parts, too, it varies with the amount of pressure to which it is subjected at different times; whence the hard hands of the artizan, compared with those of persons who have spent their time in gentler occupations. This increase in thickness probably results from the mechanical stimulus applied to the capillaries of the part. But, in whatever manner it may admit of explanation, there is scarcely a more striking instance of that inherent power which the body possesses of adapting itself to varied external circumstances, than this one presented by the human cuticle.

Fig. 83,

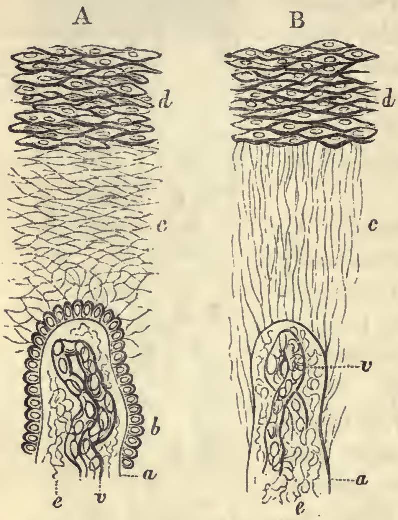


Vertical section of the sole:—*a.* Cuticle; the deep layers (rete mucosum) more coloured than the upper, and their particles rounded: the superficial layers more and more scaly. *b.* Papillary structure. *c.* Cutis. *d.* Sweat gland, lying in a cavity on the deep surface of the skin, and imbedded in globules of fat. Its duct is seen passing to the surface.—Magnified 40 diameters.

This investment is not permeated by either vessels or nerves, but consists solely of a congeries of nucleated particles, arranged in numerous superimposed laminæ, and united together by an intervening substance in very small quantity. Those particles that lie deepest, and rest immediately on the cutis, are little more than small granules, scattered in a homogeneous matrix, which serves to unite them together. Those of the next layers are rounded cells, consisting of a transparent membrane, in which similar granules, but somewhat larger in size, are visible. In the succeeding layers these cells are more and more compressed as they are nearer to the surface; and on the surface they are so flattened, that their opposite surfaces are in contact, and adhere, forming mere scales, in which the nucleus remains. The diameter of the deep particles is about $\frac{1}{3000}$ inch, and of the superficial ones $\frac{1}{600}$ inch.

We know that the superficial scales are being continually shed in small lamelliform masses, and it is evident that their loss is supplied from below; hence new particles must be constantly produced in the deepest layers, and must be in uninterrupted advance, through a series of changes, till they are cast off from the surface.* These changes are not confined to their figure: the laminæ they first form are moist, and comparatively soft, and rest like a cushion on the highly sensitive surface to which they are adapted, and whose vessels supply the materials for their development. The more external ones are hard, horny, and much drier. Schwann has also pointed out that their chemical properties become modified; that at first they are soluble, but afterwards insoluble, in acetic acid: and this circumstance of a chemical change occurring in the stages of their development seems to us so important that we shall illustrate it by two views, fig. 84, A. and B. In the former the action of weak solution of potass is shown: the layer of cells immediately resting on the basement membrane together with the more superficial scales is but slightly or not at all dissolved; while several intermediate layers are swollen and rendered very transparent, having lost their nuclei. The abruptness of the change is remarkable, and continues after the whole specimen is saturated. In the latter figure a stronger solution has been employed: the deep layer is dissolved, but the superficial scales are still unaffected, while the intermediate part is reduced to a semi-fluid mass, in which scarcely any vestige of structure remains. It is very possible that other agents might disclose further varieties of chemical constitution in smaller subdivisions of the cuticular lamellæ.

Fig. 84.



A. Section of the skin of the heel, treated with weak solution of potass:—*a*. Basement membrane of papilla. *b*. Layer of nucleated cells resting on the basement membrane. *c*. Several succeeding layers, partially dissolved and their nuclei gone. *d*. Higher layers, not affected by the menstruum. *e*. Elastic fibrous tissue of the papilla. *v*. Its capillary vessel.

B. A similar specimen, treated with strong solution of potass:—*a*, *e*, and *v*, as in A. The layer *b* is wanting, having been dissolved. *c*. Converted into a gelatinous mass with striæ. *d*. Unaffected.

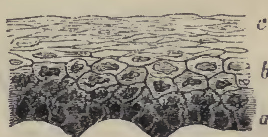
The more external layers of the epidermic scales are not represented in these figures. Magn. 150 diam.

* The cuticle of reptiles and amphibia is periodically cast off in a more or less entire state, a new one being previously formed beneath it. In amphibia the epidermis is tesselated; the scales adhering to one another by their edges, and being usually pentagonal. A similar *ecdysis*, or shedding, occurs in the larva state of insects, and in the arachnidans.

These facts will go far to explain why it happens that the union between the particles composing the same layer is in general more intimate than that between different layers, so that it is not difficult to divide the cuticle into two, three, or more laminæ: and, in particular, why it is easy, at a certain stage of maceration, to separate the harder from the softer layers, and thus to isolate the structure termed "rete Malpighii." This is nothing more than the deepest, or most recently formed, part of the cuticle. When isolated, it presents depressions, or sometimes complete apertures, which have been occupied by the projecting papillæ; and hence the term *rete*. When apertures exist, the cuticle on the top of the papillæ has been detached with the outer hard layer, and that in contact with and encircling their bases remains by itself.

In the coloured races of mankind, there is, at first sight, some ground for supposing the rete Malpighii to be a structure distinct from the other layers of the cuticle, the colouring matter being found to reside chiefly in this part. However various in quantity and hue, the colouring matter always consists of oblong or oval grains of extreme minuteness ($\frac{1}{20000}$ of an inch in their long diameter), and occupying the interior of some of the epidermic particles. In the negro it is accumulated in enormous quantity, and completely envelops the nuclei immediately resting on the cutis. On examining a vertical section of the whole cuticle, we find the colouring matter gradually diminishing as we approach the surface; and it is most clear that there is no true line of demarcation between the two portions. We may observe the colour of the rete mucosum deeper at points; and a greater proportionate depth of colour is traceable over such points, through all the layers, as far as the surface: we may even discern a sort of stream of coloured grains advancing towards the surface. Hence there can be little doubt that the decrease of colour in the superficial laminæ is due to that chemical change which has just been described as gradually taking place in the interior of the epidermic particles. As it is not always easy in this country to obtain specimens of the negro's skin, the above facts may be verified in the skin of coloured domestic animals, or, less satisfactorily, in that of some portions of the skin of the white race, as that of the scrotum, of the nipple during

Fig. 85.



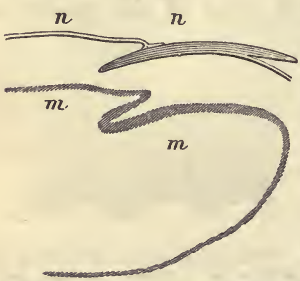
Vertical section of the cuticle, from the scrotum of a negro. *a.* Deep cells, loaded with pigment. *b.* Cells at a higher level, paler, and more flattened. *c.* Cells at the surface, scaly and colourless, as in the white races. — Magnified 300 diameters.

pregnancy, or of accidental moles, or freckles.* The bronzing of parts exposed to the sun is effected by a similar deposit of colouring matter in the deeper laminæ of the cuticle.

The subject here referred to has been invested with additional interest by its supposed bearing on the warmly-debated question of the specific difference of the negro from the white man. We need not enquire how far the existence of a distinct cuticular lamina might avail the advocates of such a difference, for we may freely state our conviction that no such peculiar layer exists. The sole variety is in the presence of pigment—which may occur, partially, under many circumstances in the white races, and may be wanting in the true negro.† The reader of the preceding paragraphs will understand how little such processes as maceration, and even the most delicate dissection by the naked eye, and with ordinary instruments, are to be depended on for the determination simply of the anatomical fact.

The *nails* and *hairs* are peculiar modifications of the epidermis, and consist essentially of nucleated particles.

Fig. 86,



Section of the skin on the end of the finger:—The cuticle and nail, *n*, detached from the cutis and matrix, *m*.

The *nails* are flattened, elastic, horny, protective coverings, placed on the dorsal surface of the terminal phalanges of the hands and feet, and projecting beyond the flesh. Hoofs, claws, etc., are varieties of them. The nail has a *root,* or part concealed within a fold of the cutis; a *body*, or exposed part, attached to the surface of the cutis; and a free or projecting *edge*. The cutis underneath the root and body is termed the *matrix,* from its being the producing organ of the nail. This is thick and highly vascular, and its colour is seen through the transparent tissue. Near the root it is white, and occasions the appearance termed *lunula*. The nail has a firm adherence to the matrix, and is moulded upon it, like the epidermis in other situations. The true epidermis (as distinguished from the nail) is continuous with the nail at the whole circumference of its body; the root dips into the fold of cutis, within the epidermis, and the free edge projects beyond it. In the advanced fœtus we find the edge of the nail to be directly continuous with the epidermis of the end

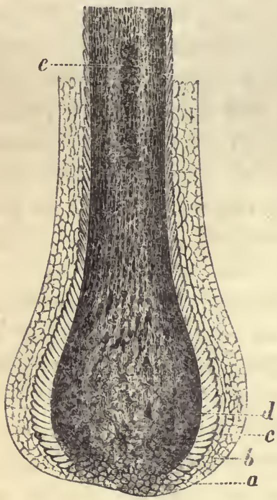
* Dr. Simon, of Berlin, has ably investigated this part of the subject.—Müller's Archiv. 1840.

† See Dr. Prichard, Natural History of Man.

of the finger, and only to become free by a rupture of this connexion after birth. Thus the nail covers that portion of cutis which is without cuticle. It has been frequently discussed whether the cuticle is continued over and under the nail; but this is a question of words only, the nail being the same essential structure as the cuticle. The border of the root of the nail is jagged, thin, and soft, and consists of newly formed substance: the deep surface of the body is also soft, and marked by longitudinal grooves, corresponding to the papillary ridges on the surface of the matrix. These soft under-parts consist of nucleated particles, similar to those of the deep layers of the epidermis. The more superficial laminæ of the nail are more and more dense and fibrous; but, when treated with acetic acid, some imperfect traces of nuclei may still be detected in them. The nail grows both at the root and on the deep surface of the body; as the substance furnished by the root advances towards the free edge, it receives accessions from the surface of the matrix.

Hairs are found on all parts of the surface, except the palms of the hands and the soles of the feet, and differ much in length, thickness, shape, and colour, according to situation, age, sex, family, or race. We may select one of average size for a description of their structure and mode of growth. The *shaft* of the hair is that part which is fully formed, and which projects beyond the surface. Tracing this into the skin, we find it lodged in a follicular involution of the basement membrane (fig. 87, *a*), which usually passes through the cutis into the subcutaneous areolar tissue. This *hair-follicle* is *bulbous* at its deepest part, like the hair which it contains. Its sides have a cuticular lining, *b*, continuous with the epidermis, and resembling the cuticle in the rounded form of its deep cells and the scaly character of the more superficial ones, which are here in contact with the outside of the hair, *c*. The hair grows from the bottom of the follicle, and the cells of the deepest stratum there resting on the basement membrane are very similar to those which in other parts are transformed into scales of cuticle. A gradual enlargement occurs in these cells as they mount in the soft bulb of the hair, which indeed owes its size to this circumstance. If the hair is to be coloured, the pigment grains are also here developed—for the most part in scattered cells, which may send out radiating processes—at other times, in a diffused manner around the nuclei of the cells generally. It frequently happens that the cells in the axis of the bulb become loaded with pigment at one period, and not at another; so that, as they pass upwards in the shaft, a dark central tract is produced of greater or less length, often only in irregular patches, and the hair appears here and there to be tubular, *e*. The shaft is much narrower than the bulb, and is produced by the rather abrupt condensation and elongation into hard fibres of the cells, both of those which contain pigment and those which do not. These fibres may be demonstrated by simply crushing small fragments of hair, but they become more conspicuous when the tissue is softened by a strong acid. The granules of pigment assume a linear arrangement between the fibres, which are firmly united into a solid rod by a material similar, it may be supposed, to that which cements the scales of the cuticle.

Fig. 87.



Bulb of a small black hair, from the scrotum, seen in section. *a*. Basement membrane of the foilicle. *b*. Layer of epidermic cells resting upon it, and becoming more scaly as they approach *c*, a layer of imbricated cells, forming the outer lamina, or *cortex*, of the hair. These imbricated cells are seen more flattened and compressed, the higher they are traced on the bulb. Within the cortex is the proper substance of the hair, consisting at the base, where it rests on the basement membrane, of small angular cells scarcely larger than their nuclei. At *d*, these cells are more bulky, and the bulb consequently thicker; there is also pigment developed in many of them more or less abundantly. Above *d*, they assume a decidedly fibrous character, and become condensed. *e*. A mass of cells in the axis of the hair, much loaded with pigment.

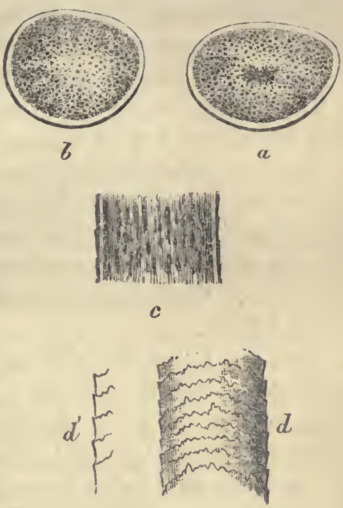
The central series of cells just mentioned, when filled with pigment, seems less disposed to become fibrous than those around; and some authors have described it as a *medulla*, in distinction from the fibrous part of the shaft, which they then term *cortex*. But the tubular character, however constant in the hair of many animals, is very variable in human hair, both in different situations, and in the same hair at different points of its length, as may be seen very well by means of transverse sections (fig. 88, *a*, *b*).*

The human hair has a proper bark, or *cortex*, formed in the following way. A single layer of the cells immediately surrounding those about to form the fibrous tissue of the shaft are seen near the bottom of the follicle to assume an imbricated arrange-

* Transverse sections of extreme thinness may be made by fixing a lock of hair between two pieces of card or wood in a vice, and then shaving it with a razor. In many animals, as the horse and dog, the hairs are tubular. In others they present a central series of cells, round or compressed, with or without pigment, as in the cat and mouse. In others again, their external surface is regularly marked by annular, and sometimes toothed projections, as in the Indian bat: and numerous other varieties might be enumerated. The quills of the porcupine, and the feathers of birds, are modifications of the epidermic tissue, and, in their essential characters, are closely allied to hairs. See Busk, in Microsc. Journal.

ment (fig. 87, *c*), and gradually to mount on the hair, becoming more compressed against it in their ascent, until they form upon its surface a thin transparent colourless film, in which the overlapping of the delicate cells is still exhibited by elegant and exceedingly fine sinuous cross lines (fig. 88, *d,d'*). The fibrous interior and this peculiar cortex together compose the shaft of the hair. By the continual emergence of fresh portions of the shaft from the follicle, fragments of the cuticular lining of the latter are apt to be drawn up upon the hair, aided, probably, in this, by the imbrication of its surface, and are often found clinging around it for some way; but they are not to be regarded as any part of the hair itself.

Fig. 88.



a. Transverse section of a hair of the head, shewing the exterior cortex, the fibrous tissue with its scattered pigment, and a central space filled with pigment. *b.* A similar section of a hair, at a point where no aggregation of pigment in the axis exists. *c.* Longitudinal section, without a central cavity, shewing the imbrication of the cortex, and the arrangement of the pigment in the fibrous part. *d.* Surface, shewing the sinuous transverse lines formed by the edges of the cortical scales. *d'.* A portion of the margin, shewing their imbrication. Magn. 150 diam.

In the larger hairs there is usually a double series of these imbricated cortical scales; the outer having its teeth interlocked with those of the inner, but apparently but loosely adherent to them. This outer series seems to be intermediate between the true cortex and the cuticle of the follicle, and to belong rather to the latter, since it does not appear upon the extended portion of the hair. The cortex is much denser than even the fibrous part of the hair, and is less acted upon by strong solution of potass.

From the preceding description, it will be evident that the fibrous part of the hair is a peculiar development of the cuticular cells resting on the bottom of the follicle, that the imbricated cortex is formed by a single series differently developed at the circumference of these, and that beyond this series comes the cuticular lining of the follicle; so that the hair is neither covered nor underlaid by cuticle, but it is, in fact, the modified cuticle of the bottom of the follicle. A thin layer of papillary tissue probably coats the bottom of the follicle in most cases; and where the hairs are large, and especially where they serve principally as tactile organs, there may be a projection of a true papilla, furnished with nerves and capillaries, into the bulb of the hair, as is very conspicuous in the whiskers of some animals and in the quills of the porcupine. An approach to this papillary projection may be frequently seen in the hairs of man; but its real size appears to have been much overrated, from the basement membrane having been overlooked. Where a papilla exists, the basement membrane is of course continued over it, and separates it from the true hair, which is never penetrated by either vessels or nerves.

The sebaceous glands of the skin very generally open into the hair follicles at a short distance from the surface.

The hair follicle is fixed more or less firmly in its place, according to the size and stiffness of the hair, by the dermoid and subdermoid tissues uniting intimately with it on its deep or convex surface, where also are spread out the capillary vessels which furnish the materials of growth. These latter are adapted in number to the dimensions of the follicle.

Thus the hairs, like the cuticle, are beautifully organized, and maintain a vital, though not a vascular, connexion with the body. Some evidence of their retaining a degree of vitality is found in the fact, first pointed out by Mandl, and verified in some instances by ourselves, that hairs have a tendency to become pointed after having been cut short off. The process is very slow, and seems to consist in a further condensation and elongation of the elementary cells at the new extremity.

Well-authenticated instances have occurred, in which the hair has grown white in a single night, from the sudden influence of some depressing passion; and some have held this circumstance a proof that fluids circulate through them. It seems most probable that this phenomenon results from the secretion, at the bulb, of some fluid—perhaps an acid, as Vauquelin supposes—which percolates the tissue of the hair, and chemically destroys the colouring matter. The ordinary gray hairs of age resemble other hairs in every respect but colour, and the process of change from dark to gray seems to take place rapidly in each individual hair.

According to Vauquelin, the colour of hair depends on the presence of a peculiar oil, which is of a sepia tint in dark hair, blood-red in red hair, and yellowish in fair hair. When extracted, as it may be by alcohol or æther, the hair is left of a grayish yellow. The colour is destroyed by chlorine, and probably otherwise resembles closely that of the cuticle in the dark races. The substance of hair is similar in chemical composition to that of horn. After being softened by maceration in cold nitric acid, it is soluble in boiling water, and the solution after evaporation becomes a gelatinous mass on cooling. The horny matter is said to be distinguishable from coagulated albumen or fibrine by its being readily soluble in caustic fixed alkalies, but not in caustic ammonia. The ashes of hair amount, according to Vauquelin, to one and a half per cent. of its weight; and contain oxide of iron, a trace of oxide of manganese, of sulphate, phosphate, and carbonate of lime, and of silica. Black hair contains most iron, and light hair least.*

Hairs, when dry and warm, are easily rendered electrical. They readily attract moisture from the atmosphere, and no doubt from the body also, yielding it again by evaporation, if the air be dry. When moist, they elongate considerably; a property which Saussure took advantage of in the construction of his hygrometer, in which a human hair, by its elongation and shortening in moisture and dryness, is made to turn a delicate index.

The shape of the hairs in different situations offers some variety. In general, they taper towards their free end. Those of the head are often not cylindrical, but compressed on one or both sides, so that their transverse section is reniform or oval. The eye-brows and eye-lashes taper towards both extremities. Hairs also vary in being lank or woolly, permanent or deciduous. The frizzled hair of the negro is one of his most remarkable characteristics, but has all the essential structural characters of the hairs of the other races.

The diseased condition called *plica Polonica* is a matting together of the hairs, from the effusion of a glutinous matter, probably from the cutaneous glands. It is said that hairs so affected bleed, if cut close to the skin. This, if true, may result from a morbid elongation of the vascular papillæ at their roots. In the whiskers of large animals these papillæ are so long, that they are cut and bleed if the whiskers are shaved off.

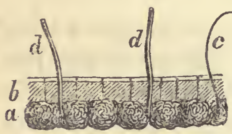
In some regions of the skin it appears certain that a *lymphatic network* exists immediately under the surface of the cutis, probably under its basement membrane. Mercury injected into this network through a puncture in the cuticle passes readily into the neighbouring lymphatic trunks, and removal of the cuticle does not injure its meshes. These circumstances may be observed in the penis, scrotum, and nipple: but it is probable that the network sometimes exhibited by this procedure in other parts of the skin, is a fallacious appearance due to the mercury having insinuated itself between the cutis and cuticle, in the furrows at the base of the papillary structure; for it does not find its way into the lymphatic trunks, and is deranged by a complete separation of the cuticle.†

* Baly's Müller, p. 424–5, quoted from Berzelius.

† Cycl. of Anat. and Phys.; *art.* Lacteal and Lymphatic System: by Mr. Lane.

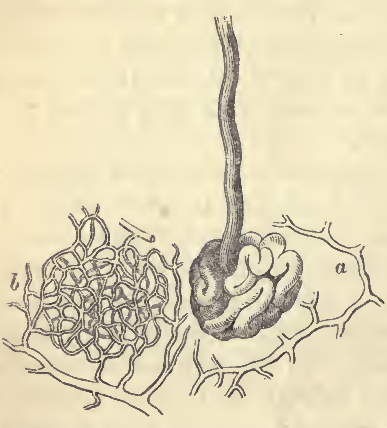
The *sweat-glands* exist under almost every part of the cutaneous surface. They lie in small pits (fig. 83, *d*) on the deep aspect of the cutis; or, if large, entirely in the subcutaneous fascia. As before mentioned, their orifices are discernible in the middle of the cross grooves that intersect the ridges of papillæ on the hands and feet. Here their arrangement is necessarily regular, and their size is about that of a pin's head. But in other parts they are irregularly scattered, though in general in pretty equal numbers over areas of the same dimensions. In certain situations, however, they are very large; and, as might be expected, we find their size and number in different districts of the skin to correspond with the amount of perspiration afforded by each. Thus, they are nowhere so remarkable, or so easily examined, as in the axilla, over a space precisely defined by the growth of the hair in the adult. They here form a layer, which, towards the middle, is often an eighth of an inch thick, but thinner towards the edge. It is of a reddish colour, and mammellated by the individual glands which compose it. Some of these are as large as the labial glands, but most of them are somewhat smaller. They are soft, and more or less flattened by lateral apposition with one another, They lie in an atmosphere of delicate areolar tissue, and are covered and permeated with a network of capillary blood-vessels.

Fig. 28.



Vertical section of the skin and sweat-glands of the axilla:—*a*. Layer of glands with their ducts traversing *b*, the cutis and cuticle. *c*. Small hair. *d*, *d*. Portions of larger hairs. —Magnified one and a half diam.

Fig. 90.

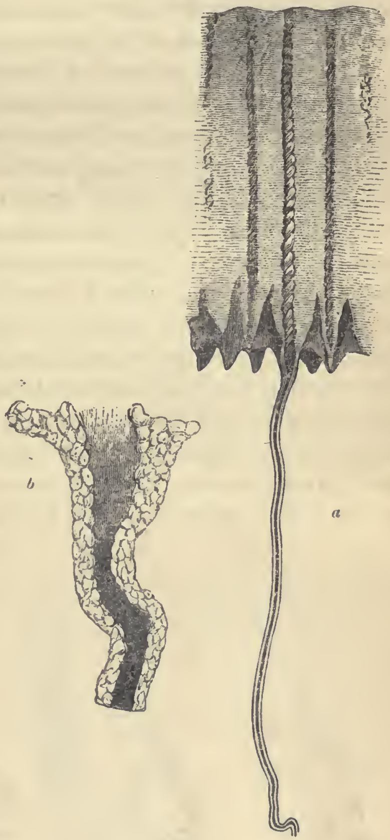


Sweat-gland and the commencement of its duct:—*a*. Venous radicles on the wall of the cell in which the gland rests. This vein anastomoses with others in the vicinity. *b*. Capillaries of the gland separately represented, arising from their arteries, which also anastomose. The blood-vessels are all situated on the outside or deep surface of the tube, in contact with the basement membrane.—Magnified 35 diameters.

The sweat-glands can be shown, wherever they exist, by dissecting a piece of fresh integument on its deep surface. They are distinguishable from the pellets of fat, with which they have doubtless been repeatedly confounded, by their pink colour and semi-transparent texture. Where the areolar framework of the cutis is densely interwoven, they are less readily discerned, but injection of the blood-vessels makes their detection easy.

On detaching one of these glands, and highly magnifying it, it is seen to consist of a solitary tube intricately ravelled, one end of which is closed, and usually buried within the gland ; the other emerges from the gland, and opens on the skin. Sometimes this tube is branched, but its diameter is usually very uniform from end to end. When very long, the open end forming the duct is a little wider than the rest. The wall is comparatively thick, so that the calibre is not more than a third of the whole diameter. It consists, like the corresponding part of most other glands, of two layers : an outer or *basement membrane,* with which the vessels are in contact ; and an *epithelium,* lining the interior. The basement membrane is extremely thin, and is continuous with the outer surface of the papillæ. The epithelium is much thicker, and is an involution of the epidermis that rests on the papillæ and dips in between them. Hence the tube, traced outwards from the gland, loses the basement membrane at the surface of the papillæ ; and the remainder of its course is pursued upwards through the successive laminæ of cuticular scales.

Fig. 91.



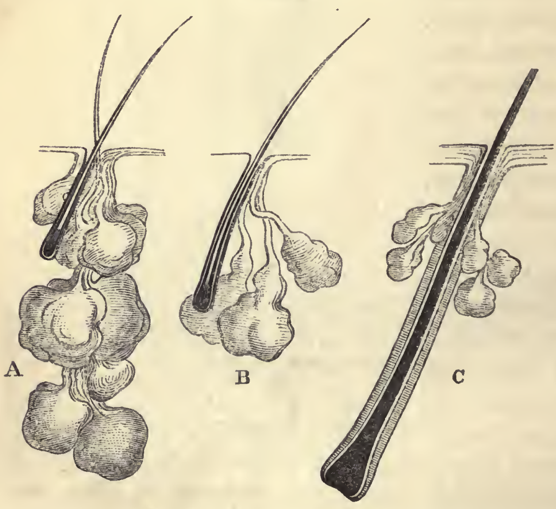
a. Vertical section of the cuticle from the heel, detached by maceration as in fig. 79. The epithelium of the sweat-duct, continuous with the cuticle, has been drawn out of the tube basement, membrane, as far as the gland, where it begins to be contorted. The cavity of the duct is seen dilating as it enters the cuticle, and then stretching up to the surface through the epidermic laminæ. The deep surface of the duct is continuous with the surface of the cavities in which the papillæ are lodged.—Magn. 35 diam.

b. Duct at its entrance into the cuticle. — More highly magnified.

The preparation exhibited in fig. 91 shows the continuity of the epithelium lining the excreting part of the duct with the cuticle, and also discloses its hardness and cuticular character, quite different from that of the secreting epithelium within the gland, which is soft and easily decomposed. We have remarked that the duct, in traversing the layers of the cuticle, is lined by epidermic particles having a different arrangement from those of the cuticle itself; being flattened in the vertical instead of the horizontal direction, and especially distinct in the deeper and softer stratum of the cuticle. This special cuticular tunic of the duct is best exhibited by treatment of recent specimens with solution of potass.

The duct, on leaving the gland, follows a meandering, and often rather spiral direction, through the areolæ of the cutis, to the interval between the papillæ, where it becomes straight; and it again assumes a spiral course in perforating the cuticle (fig. 83). In the cutis its curves are unequal, elongated, and wide; but, in the cuticle, they are commonly as close and regular as those of a common screw, the form of which may be taken as a fair model of the ducts in this part. It is not easy to explain the mode in which the spiral form is given to the cuticular part of the duct. It has been imagined to result from the condensation and flattening of the laminæ of epidermis as they approach the surface; but the fact, that the spirals are not closer near the orifice, is opposed to this notion. Their use, also, is obscure; for we cannot admit the validity of the ingenious idea that the orifice of a spiral tube must be valvular, and, therefore, that they mechanically resist the entrance of foreign substances. If they do offer this opposition, it is only by the tortuosity resulting from the spiral arrangement. The proper tunic of the duct in the substance of the cuticle seems designed to keep it pervious, and may be that which gives it its peculiar spiral form. The average diameter of the cavity of the duct is $\frac{1}{1700}$ inch but, as it enters the cuticle, it usually becomes wider.

Fig. 92.



Sebaceous glands, showing their size and relation to the hair-follicles:—A and B from the nose; C from the beard. In the latter the cutis sends down an investment to the hair-follicle.—Magnified 18 diameters.

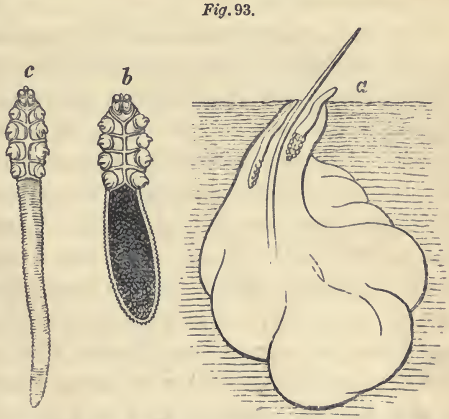
The last two figures, as well as some of the preceding ones, illustrate the anatomy of the sweat-glands.

The *sebaceous glands* are found

in most parts of the skin, but are absent from the palms and soles. They are most abundant on the scalp and face (especially about the nose), and about the anus and scrotum. The *glandulæ odoriferæ* of the genital organs are a variety of them, only remarkable by their secretion. The orifices open either on the general surface, or into the hair-follicles, and they lie either in the cutis or subdermoid tissue, according to their size. They are usually associated with the hairs, in the manner represented in fig. 92. They consist of a more or less capacious duct, generally branched, and terminating in blind, pouch-like extremities. The basement membrane of these glands is thicker than that of the sweat-glands, and is lined by an epithelium, in the particles of which are included granules of sebaceous matter. The terminal vesicles and the ducts are filled with an accumulation of this epithelium, which, having been detached from the walls, constitutes the secretion. On the deep or parenchymal surface of the basement membrane a web of capillary vessels is spread out.

While speaking of the sebaceous glands, we must say a few words of a parasite so generally found in their ducts in many parts of the body, that it may almost be regarded as a denizen. This was recently discovered by Dr. Simon, of Berlin,* and has been further described by Mr. Wilson,† who speaks of two principal varieties of the adult animal, chiefly distinguished by their length; the one measuring from $\frac{1}{100}$ to $\frac{1}{45}$, the other from $\frac{1}{100}$ to $\frac{1}{109}$ of an inch. He details several interesting particulars concerning their structure and development, for which we must refer to the original memoir. These singular animals "are found in almost every individual, and especially in those possessing a torpid skin, and they multiply in sickness. In living and healthy persons from one to three or four may be found in each follicle." We have represented them as we have found them in a sebaceous follicle of the scalp (fig. 93).

Fig. 93.



Entozoa from the sebaceous follicles. — *a*, Two seen in their ordinary position in the orifice of one of the sebaceous follicles of the scalp. *b*. Short variety. *c*. Long variety.

* Müller's Archiv., June, 1842. † Phil. Transact. 1844.

The *ceruminous glands* of the ear resemble in their structure those just described. They exist in great abundance in the skin of the cartilaginous part of the external meatus, and provide an adhesive secretion calculated to entangle particles of dust and small insects, and to prevent their access to the delicate membrane of the tympanum.*

Of the Functions of the Skin.—Having now considered the several constituents of that very complicated organ, the skin, it remains for us to take a brief general view of its functions before proceeding to a particular account of that one which brought us to this structure, viz. the sense of touch. All these functions have reference to its external anatomical position with respect to the other structures of the body. Regarded as a protective covering, the skin possesses the united advantages of toughness, resistance, flexibility, and elasticity. The areolar framework of the cutis is the part chiefly conferring these properties, which are due also in some measure to the epidermis. Both these structures are developed in a degree proportioned to the force and frequency of external contact to which different regions of the body are liable. They are thickest on the palms and soles, on the back of the trunk, and the outer surface of the limbs: thinner on the front of the body, and on the inside of the limbs.

These two elements also afford protection and support to the other more delicate ones with which they are associated. The areolæ of the cutis sustain the intricate networks of blood-vessels, lymphatics, and nerves, which traverse it. The sweat-glands are imbedded in cavities accurately fitted to receive them; and their ducts, with the sebaceous follicles and hairs, are all lodged in channels or spaces adapted to their respective sizes. The epidermis is a defensive investment to the tactile organ, and, while it shields it from the injurious effects of pressure, is the medium through which impressions of contact are conveyed to it with admirable nicety and truth. The epidermis furnishes also special organs, such as nails and hairs; which are developed in particular situations, for the purposes of defence, the preservation of warmth, or as aids to the sense of touch. The infinite variety of modifications which the epidermis presents among the lower animals, joined with others of nearly equal diversity in the neighbouring textures, adapts it to very numerous and even opposite uses in the animal kingdom.

* In the sharks and rays there is a remarkable system of mucous tubes opening on the skin. These tubes are nearly as large as crow-quills, and of great length. They end by a blind extremity, to which a small nerve of the fifth pair is attached.

The skin combines the opposite functions of *absorption* and *secretion.* Its lymphatic network, and the capillaries, are both concerned in the former, which, under certain conditions, is very actively performed.

Secretion may be said to be carried on at every point of the surface of the cutis, since the cuticle is a deciduous product, constantly in course of separation from it. But the principal seat of this function are those glandular offsets from the skin that lie scattered in numberless multitudes beneath it. It may be safely said, that the secreting membrane they comprise far exceeds, in extent, the surface of the whole body. By the involutions of the sweat-glands, the surface is multiplied, for the sole purpose of secretion, and the quantity of material capable of being thus eliminated is enormous. There is one peculiarity connected with this great glandular surface, which results from its not being made up into a solid organ, but disseminated in detached points under the integument, viz., that it is more than all others subject to the influence of external temperature, acting upon the cutaneous blood-vessels; but an apparatus for adjusting the irregularities hence resulting is provided in the kidneys, as will be hereafter explained.

The sebaceous glands are another great system, chiefly subservient to the protection and health of the skin itself, but resembling the sweat-glands in their disseminated arrangement. They are extremely numerous, and yield an oily material for the lubrication of the surface of the cuticle. On most parts of the body they are as abundant as the hairs themselves. They are an important accessory organ for the elimination of hydro-carbonous matters from the system. Thus the skin is a superficial emunctory of great extent and importance, and will demand subsequent consideration in that character.

We may now consider the function of the skin as the *organ of touch.* One of the distinguishing characteristics of this sense is its universal diffusion over the exterior of the body, by which its sphere of action as a recipient of impressions, and as a criterion of locality, is rendered more extensive than that of any other. The contact of foreign bodies is perceived as occurring at the point at which they actually strike the organ of touch, whether that point be within the sphere of operation of any other sense or not. The precision with which this is effected depends very much on the degree of development of the papillary tissue in the several regions of the body.

We have already seen that the papillæ present great varieties in different parts. These varieties will be found to correspond very much with differences in the mobility of such parts. In general, touch is most acute in regions best suited, by their structure, for easy and diversified contact with external substances; for the power of nicely determining the position, direction, and amount of pressure upon the organ of touch, is essential to the perfection of the sense. The will can not only excite and check the contractions of the muscles, but is able to regulate their force and duration with wonderful precision; for, by the *muscular sense,* as stated in a previous chapter, the mind is able to appreciate the state of contraction of a muscle by impressions originating in the nerves supplied to its fibres. This power, both of recognizing and governing the muscular movements, is from our earliest infancy brought into association with the impressions derived from the tactile organ, and made accessory to its function; and the perfection to which habit, in numerous instances, brings the sense of touch, is chiefly due to an improved capacity it confers, of appreciating the impressions made on the organ, in connexion with niceties of muscular movement.

In animals, as in man, we may notice the local concentration of the sense in general obedience to this relation of mobility. In monkeys the fingers are highly endowed with it, and the papillæ there developed closely resemble those on the human hand. The prehensile tails of certain tribes possess great mobility, can readily be applied all round an object, and are largely supplied with nerves and papillæ. In addition to this, there is an absence of hair from that surface adapted for contact with bodies. In some ant-eaters the tail is highly tactile, and likewise in the chameleon.

In the canine and feline races the sense of touch resides in the paws, which present a large papillary structure; in the lips, where the whiskers are developed; and in the tongue. In ruminants and solipeds it has its special seat in the lips, which are long, very moveable, and largely supplied with sensitive and motor nerves. The upper lip of the rhinoceros is an excellent example of these conditions; and, still more so, the snout of the tapir and the trunk of the elephant, where the integuments about the orifice of the nostrils are endowed with exquisite powers both of sense and motion.

But nowhere, perhaps, is the sense of touch more acute than in the membranous expansions of the wings of bats, whereby they are enabled to traverse dark and tortuous passages, in rapid flight, without injury. Spallanzani blinded them with a view of determining whether sight conferred any part of this singular power, but found that this mutilation interfered in no respect with the faculty. They were still able to fly in the space between suspended threads without touching them. He could not conceive it possible that so wonderful an endowment could depend on any exaltation of mere touch, and he resorted to the supposition of the existence of a sixth sense, possessed of some unknown mode of action. But Cuvier, with more sagacity, has referred it to an eminent sensibility of the nerves, which are profusely expanded over the web of the wings. This membrane seems admirably calculated to receive exact impressions from the vibrations of the air, and so to be a means whereby the animal may be informed of the distance and figure of the neighbouring objects, which reflect or otherwise modify the undulations of the surrounding medium. It is very probable that hearing also may be concerned in this power.

In men, as compared with animals, the sense of touch is extensively diffused; but very interesting differences in its intensity are observable in different parts of the surface, which have been especially illustrated by the experiments of Weber.

These consisted in placing the two points of a pair of compasses, blunted with sealing-wax, at different distances asunder, and in various directions, upon different parts of the skin of an individual, who was not permitted to see the bodies in contact with him. It was then found, that the smallest distance at which the contact can be distinguished to be double, varies in different parts between the thirty-sixth of an inch and three inches; and this seems a happy criterion of the acuteness of the sense. We recognize a double impression on very sensible parts of the skin, though the points are very near each other; while, in parts of obtuse sensibility, the impression is of a single point, although they may be, in reality, far asunder.

In many parts we perceive the distance and situation of two points more distinctly when placed transversely than when placed longitudinally, and *vice versâ*. For example, in the middle of the arm or fore-arm, points are separately felt at a distance of two inches, if placed crosswise; but scarcely so at a distance of three, if directed lengthwise to the limb.

Two points at a fixed distance apart feel as if more widely separated when placed on a very sensitive part, than when touching a surface of blunter sensibility. This may be easily shewn by drawing them over regions differently endowed; they will seem to open as they approach parts acutely sensible, and *vice versâ*.

If contact be more forcibly made by one of the points than by the other, the feebler ceases to be distinguished: the stronger impression having a tendency to obscure the weaker, in proportion to its excess of intensity.

Two points at a fixed distance are distinguished more clearly when brought into contact with surfaces varying in structure and use, than when applied to the same surface, as, for example, on the internal and external surface of the lips, or the front and back of the finger.

Of the extremities, the least sensitive parts are the middle regions of the chief segments, the arm, fore-arm, thigh, and leg. The convexities of the joints are more sensible than the concavities.

The hand and foot greatly excel the arm and leg, and the hand the foot. The palms and soles respectively excel the opposite surface, which are even surpassed by the lower parts of the fore-arm and leg. On the palmar aspect of the hand the acuteness of the sense corresponds very accurately with the development of the rows of papillæ; and where these papillæ are almost wanting, as opposite the flexions of the joints, it is feeble.

The scalp has a blunter sensibility than any other part of the head, and the neck does not even equal the scalp. The skin of the face is more and more sensible as we approach the middle line; and the tip of the nose and red part of the lips are acutely so, and only inferior to the tip of the tongue. This last, in a space of a few square lines, exceeds the most sensitive parts of the fingers; and points of contact with it may be generally perceived distinctly from one another, when only one-third of a line intervenes between them. As we recede from the tip along the back or sides of the tongue, we find the sense of touch much duller.

The sensibility of the surface of the trunk is inferior to that of the extremities or head. The flanks and nipples, which are so sensitive to tickling, are comparatively blunt in regard to the appreciation of the distance between points of contact. Points placed on opposite sides of the middle line, either before or behind, are better distinguished than when both are on the same side.

The above are the results obtained by making the several parts mere passive and motionless recipients of impressions. They evince the precision of the sense in so far only as it depends on the organization of the tactile surface. The augmented power derived from change of position of the object with regard to the surface, is well illustrated by keeping the hand passive, while the object is made to move rapidly over it. In this case the contact of the two points is separately perceived, when so close, that they would, if stationary, seem as one. If, still further, the fingers be made to freely traverse the surface of an object, under the guidance of the mind, the appreciation of contact will be far more exquisite, in proportion to the variety of the movements, and the attention given to them. We are then said to *feel*, or to examine by the sense of touch.

How great is the aid thus capable of being afforded, is manifest in the following experiment. With shut eyes, and the hand still, let another apply to the finger various articles, such as books, paper, glass, metals, wood, cork, &c.; they will be very imperfectly distinguished. That our power of varying the force of contact adds much to the delicacy of touch, is evident from this: that a plane surface may be made to seem concave, by drawing it over the passive tip of the finger of a person whose eyes are covered, provided it be pressed at first strongly, then lightly, then strongly again; or it may be made to seem convex by reversing these gradations of pressure. But, if the individual himself is the regulator of the pressure, the deception vanishes. We may obtain some knowledge of the irregularities of surfaces, and the shape of objects, by simply bringing the tactile organ into contact with them; but much more by moving it over them with attention. Thus, too, the infinite diversities of texture may be made distinguishable by the education of tact, combined with that of the muscular sense. It is related of Saunderson, the blind professor of mathematics at Cambridge, that he could distinguish a spurious from a genuine medal, when the deception had imposed upon connoisseurs; and the case of the blind man, referred to by Rudolphi, who was able to distinguish between woollen cloths of different colours, of course by some slight variety in their texture, is rendered credible by many well-attested examples of a parallel kind.

Our power of appreciating the *weight* of bodies, as well as resistances in general, depends on those of estimating, separately and in concert, both pressure on the tactile organ and the amount of contractile energy acting in the muscles. Weber performed experiments to ascertain how far we are capable of judging of weight by the mere sense of contact. He found that when two equal weights, every way similar, are placed on corresponding parts of the skin, we may add to or subtract from one of them a certain quantity without the person being able to appreciate the change; and that when the parts bearing the weights, as the hands, are inactively resting upon a table, a much greater alteration may be made in the relative amount of the weights without his perceiving it, than when the same parts are allowed free motion. For example, 32 ounces may thus be altered by from 8 to 12, when the hand is motionless and supported; but only from $1\frac{1}{2}$ to 4, when the muscles are in action: and this difference is in spite of the greater surface affected (by the counter pressure against the support) in the former than in the latter case. Weber infers that the measure of weight by the mere touch of the skin is more than doubled by the play of the muscles. We believe this estimate to be rather under than over the mark.

The relative power of different parts to estimate weight corresponds very nearly with their relative capacities of touch. Weber discovered that the lips are better estimators of weight than any other part, as we might have anticipated from their delicate sense of touch and their extreme mobility. The fingers and toes are also very delicate instruments of this description. The palms and soles possess this power in a very considerable degree, especially over the heads of the metacarpal and metatarsal bones; while the back, occiput, thorax, abdomen, shoulders, arms, and legs, have very little capacity of estimating weight.

Heat and *cold* are pecular sensations excited by alterations of temperature on the surface of the body. They are, beyond all other sensations, of a relative rather than of an absolute kind, and are always most marked in contrast. Thus, in the familiar experiment of dipping one hand into hot, and the other into cold water, and then plunging them both into water of an intermediate temperature, the new medium will seem cold to the former and hot to the latter; and natives of the polar and tropical regions of the globe will respectively complain of the warmth or chilliness of our temperate climate when they visit our shores. But it is observable that the sensations of heat and cold, when exalted in degree, resemble each other very nearly. The susceptibility to both is greatest within moderate limits; and impressions of either, when acute and powerful, amount to pain, and soon cease to be distinguishable from one another.

Temperature appears higher in degree when it is applied to a larger surface: thus water feels hotter when we put our whole hand into it, than when we only dip a finger; the extent of the sensation augmenting the intensity with which it is appreciated, perhaps by more forcibly attracting the attention.

Sensations of temperature have been usually, and we believe properly, attributed to the nerves of common sensation. These sensations are certainly quite different from touch, both in their peculiar characters and in the source of excitement; but no less may be said of various other modifications of common sensation, to which it is impossible to assign nerves of special endowment. The existence of fibres fitted to be acted on by heat and cold, but by no other stimulus, may be fairly doubted so long as they are undistinguishable from those of touch both at their origin from the nervous centre and in their peripheral distribution. Still, however, it may be noted, that in certain states of paralysis, the sensibility to heat and cold may be destroyed, while common sensation and touch remains.*

* See an instructive case by Dr. W. Budd, in the Med. Chir. Trans. vol. xxii.

The sensations of tickling, tingling, itching, and many others allied to them, are also referrible to the nerves of touch. Respecting tickling, it has been well observed by Weber, that it is most apt to be excited in parts of feeble tactile power.

Impressions made on the organ of touch, as on the other organs of sense, continue perceptible for a period more or less prolonged after the stimulus has ceased to be applied. The sting of a smart blow does not soon subside; and even the simple contact of any object, as a ring or an article of clothing, with a part of the skin, if long continued enough, leaves, after its removal, an impression of its presence, which is apt to deceive the individual for a considerable time. The influence of habit on sensation in general, may be well illustrated in the case of the nerves of common sensation and of touch. Impressions sufficiently strong in the first instance to arouse the attention, soon become feeble, and in time wholly disregarded, if continued uniformly or frequently repeated; although the mind can still, at any moment, take cognizance of them by a voluntary effort. The sensations of heat and cold may, by long habit, in like manner come to be unnoticed, or lightly heeded, within certain bounds. This is a matter of common experience, and may be exemplified in the case of the lower classes of society, among whom the privation of the comforts of warm clothing and lodging, and the absence of the mistaken luxury of over-heated rooms, are compensated for by the possession of that diminished susceptibility to cold, under slight exposures, which is so remarkable in those subject, in a moderate degree, to the inclemencies of the seasons.

Little needs be said of the subjective sensations pertaining to the nerves now under consideration. They are among the best known, and most familiar in the body. The peculiar tingling of a limb "asleep," which commonly depends on pressure on its trunk, may result from morbid changes in the centre; as may likewise sensations of formication, or the creeping of insects, and those of itching, of heat, of chilliness, etc., and lastly of pain of various kinds.

Besides the references in the foot-notes and the various treatises on Physiology and General Anatomy already cited, we may refer on the subject of the preceding chapter to Rudolphi, Grundriss der Physiologie, band ii.;—Weber, de pulsu, resorptione, auditu, et tactu; Lips. 1834;—Breschet et Roussel de Vauzème, Ann. d. Sciences Nat. 1834, tom. i.;—Schwann, Mikroskop. Untersuchungen;—Eble, die Lehre von den Haaren;—Gurlt, Müller's Archiv. 1836;—Van Laer, de structurâ capillorum humanorum; Traj. ad Rhen. 1841.

CHAPTER XV.

OF TASTE.—OF THE MUCOUS MEMBRANE OF THE TONGUE, AND OF ITS SIMPLE AND COMPOUND PAPILLÆ.—NERVES OF TASTE.—NERVES OF TOUCH IN THE TONGUE.—SEAT AND PHENOMENA OF TASTE.

THE sense of taste is subservient to the nutritive function by guiding us in the discrimination of the qualities of our food, and is therefore appropriately situated in the mouth, the antechamber to the digestive canal. The food being delayed more or less in this cavity, is brought, by the movements to which it is exposed, into intimate and varied contact with the surface; and, its properties being ascertained while it is still under voluntary controul, we are able to reject it or to propel it onwards, according to the impression produced on the nerves of taste.

The mucous membrane of the tongue, as the principal seat of the sense, will now demand description. The muscular apparatus of this organ, though increasing its powers of taste, relates chiefly to its employment in the processes of mastication and deglutition, and will therefore be considered at a future page.

In the mucous membrane of the tongue we find a *chorion*, a *papillary structure*, and an *epidermis* or *epithelium;* all corresponding, in essential characters, with the same constituents of the skin.

The *chorion*, or *cutis*, is tough, but thinner and less dense than in most parts of the skin: it receives the insertion of all the intrinsic muscles of the tongue, which send up their fibres to it in small separate bundles, so that the surface of the tongue is exceedingly mobile, even in its minute portions, and its powers as an organ of touch are thereby much exalted. The termination of the muscular fibres in the fibrous tissue of the chorion can be well seen in thin vertical sections. The chorion contains the ramifications of the vessels and nerves from which the papillary structure is supplied. Both the arteries and veins form plane plexuses, open on all sides, like those of the skin, and respectively connected with the vessels of the papillæ above them.

The *papillary structure* has, in general, this peculiarity, that it is not concealed under the epithelium, but stands out freely from the surface, like the villi of the intestinal tube, occasioning the familiar roughness of the tongue. This, however, is to be taken with the limitations hereafter to be detailed.

The *epithelium* of the tongue is of the scaly variety, and in this respect resembles the cuticle. Like the cuticle, also, it undergoes certain modifications in its mode of aggregation in different localities. In general it is much thinner than in the skin, so that the intervals between the large papillæ are not filled up by it, but each has a separate investment, from root to summit. The continuity of the epidermis over the whole organ admits of easy demonstration by maceration, or boiling; by which it is detached entire, bearing the print of the surface below, on which it has been moulded. The deeper epithelial particles may sometimes be detached as a separate sheet, corresponding to the so-called *rete mucosum;* but these particles never contain colouring matter. In animals which have the epithelium of the tongue much thicker than in man, it admits of being separated with care into a great many layers, at the will of the anatomist. The density of the epithelium is evidently a provision to defend the invested structure from the bad effects of the pressure and friction to which they are exposed during mastication, and hence it is greatest about the middle of the upper surface of the organ. It is here that the "fur" usually accumulates most in disease, being, in fact, no other than a depraved and overabundant formation of the epithelium.

Three principal varieties of *papillæ* are visible with the naked eye on the dorsal aspect of the tongue. These are, 1, the *circumvallate* or *calyciform*, eight or ten in number, situated in a V-shaped line at the base of the organ (fig. 94, *a*); the *fungiform*, scattered over the surface, especially in front of the circumvallate, and about the sides and apex, *b;* and the *conical* or *filiform*, much the most numerous, studding most of the surface, though most largely developed in the central part, *d*. These three varieties will require a separate description; they are very distinct from one another if well-marked specimens are selected; but, as might be expected, there are many intermediate forms by which they seem to run imperceptibly into one another. We may premise, however, with regard to them all, that although they appear to have been hitherto regarded as simple papillæ, analogous to, though larger than, those of the skin, yet we have found them to be compound organs, clothed with secondary, simple, and much more minute papillæ, concealed under the epithelial investment, and scarcely or not at all visible until this covering is removed.

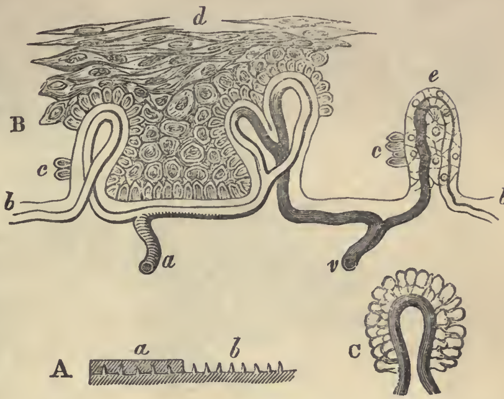
Fig. 94.

Tongue seen on its upper surface:—*a*. One of the circumvallate papillæ. *b*. One of the fungiform papillæ. Numbers of the conical papillæ are seen about *d*, and elsewhere. *e*. Glottis, epiglottis, and glosso-epiglottidean folds of mucous membrane.—From Sœmmering.

In their compound nature they present much resemblance to the intestinal villi of the rhinoceros and other large animals. We have further ascertained the existence of similar minute papillæ, interspersed very unequally among the compound forms, as well as occupying much of the surface behind the circumvallate variety, where the compound forms do not exist. These minute papillæ seem to have hitherto escaped detection, in consequence of their being completely buried and concealed under the common sheet of epithelium.

If we examine the mucous membrane immediately in front of the epiglottis, we find it perfectly smooth, almost transparent, and supplied by capillary vessels spread uniformly under the surface, and connected with simple plain submucous plexuses of arteries and veins: here the papillary tissue is undeveloped. Further forwards, however, where the membrane, still seems smooth, the plexus of arteries beneath it sends upwards, at pretty regular intervals, a series of twigs, each of which terminates in one or two capillary loops, sometimes dilated in the bend, from which a small vein returns the blood to the submucous venous plexus. These loops correspond to those of the simple papillæ of the skin, p. 411; they supply simple papillæ, buried under a common investment of scaly epithelium, that differs from the cuticle only in its greater tenuity and moistness. On the removal of this delicate epithelium by maceration, the papillæ stand out free from the membrane, and are seen to consist of an envelop of basement membrane (p. 404), enclosing a parenchyma obscurely granular, with the capillary loop already mentioned. After much care, we have not been able to see nervous tubules within them; but they must exist under some important modification, which most probably consists in the absence of their characteristic white substance of Schwann. These simple papillæ are represented in fig. 95.

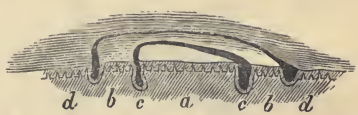
Fig. 95.



Similar papillæ near the base of the tongue:—A. *a*. concealed under the epithelium; *b*. uncovered by it.—Magnified 10 diameters. B. *a*. Arterial twig, supplying their capillary loops. *v*. Vein. The vessels are all contained within the line *b*, *b*, of basement membrane. *c*, *c*. Deeper epithelial particles resting on the basement membrane. *d*. Scaly epithelium on the surface. The granular interior of the papillæ is represented at *e*. C. Papillæ in which the basement membrane is not visible; and the deep layer of epithelium seems to rest on the capillary loop. Magnified 200 diam.

The *circumvallate papillæ* (fig. 94, *a*, and fig. 96) consist of a central flattened projection of the mucous membrane of a circular figure, and from $\frac{1}{20}$ to $\frac{1}{12}$ of an inch wide, surrounded by a tumid ring of about the same elevation, but less diameter, from which it is separated by a narrow circular fissure, with, it is said, a few mucous ducts opening at the bottom. In the smaller examples this fissure exists only on one side. The surface of both centre and border is smooth, and invested by scaly epithelium, concealing a multitude of simple papillæ, in all respects similar to those just described.

Fig. 96.

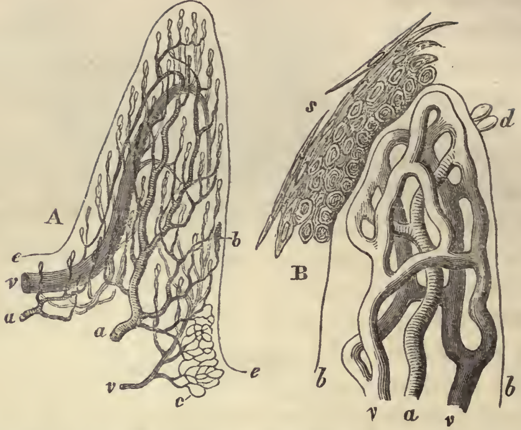


Vertical section of one of the circumvallate papillæ:—*a*. Central part. *b*, *b*. Border. *c*, *c*. Fissure between centre and border. The secondary papillæ are seen covered by the epithelium. Similar papillæ are seen, *d*, *d*, on the membrane beyond.—Magn. 8 diam.

About the point where the two lines of circumvallate papillæ meet, there is usually one with the fissure so large and deep as to have received the name of *foramen cæcum*. The central part is frequently small, or elongated and thrown on one side of the foramen. In the specimen next represented (fig. 97), this is shewn covered with secondary papillæ, having all the characters of those above mentioned. In its interior we failed to detect any nerves provided with white substance. In this region of the tongue fissures and papillæ of irregular size and shape are often met with, and mucous glands are disseminated beneath the surface.

The *fungiform* papillæ (fig. 94, *b*, and fig. 98) are scattered singly among the filiform papillæ, chiefly on the sides and tip of the tongue, and very sparingly in the middle of the dorsal region. They are usually narrower at their base than summit, where they are from $\frac{1}{25}$ to $\frac{1}{35}$ of an inch in diameter. Like those last described, they

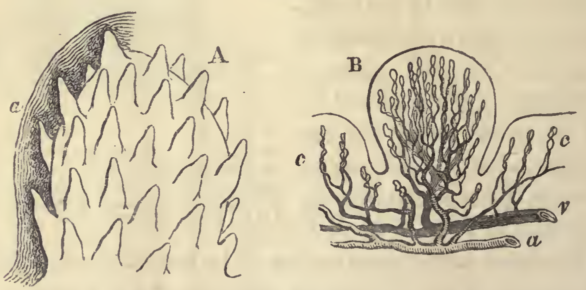
Fig. 97.



A. Compound papilla on the side of the foramen cæcum, injected :—*a*, *a*. Arterial twigs. *v*, *v*. Veins. The capillary loops indicate the simple papillæ; in one of which, *b* the injected matter has been extravasated within the basement membrane of the papilla, the outline of which is thus distinguished. *c*. Capillary plexus, where no papillæ exist. *e*, *e*. External surface of the epithelium of the papilla.—Magn. 15 diam.

B. One of the simple papillæ of A. :—*a*. *v*, *v*, Arterial and venous sides of the capillary loops. *b*, *b*. Basement membrane. *d*. Deeper epithelial particles resting on the basement membrane. *s*. Scaly epithelium on the surface.—Magn. 300 diameters.

Fig. 98.



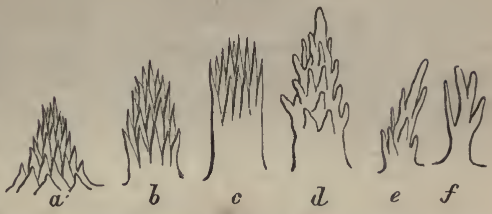
A. Fungiform papilla, shewing the secondary papillæ on its surface, and at *a* its epithelium covering them over.—Magnified 35 diameters.

B. Another, with the capillary loops of its simple papillæ injected. *a*. Artery. *v*. Vein. The groove around the base of some of the fungiform papillæ is here represented, as well as the capillary loops, *c*, *c*, of some neighbouring simple papillæ.—Magnified 18 diameters.

are clothed with simple papillæ; and their investing epithelium is so thin, that the blood, seen through it, gives them a red colour, usually sufficient to distinguish them from the filiform ones among which they lie. They contain nerve-tubes, having a loop-like arrangement.

The compound papillæ of the third variety (fig. 94, *d*, and figs. 99 and 100) are of the average length of $\frac{1}{10}$ of an inch, and, as their name implies, are more or less *conical* or *filiform* in shape. They are distinguished moreover by their whitish tint, derived from the thickness and density of their epithelium. This, indeed, frequently composes two-thirds of their length, being sent off from the sides and summits of their secondary papillæ in long pointed processes, which are immersed in the mucus of the mouth, and may be moved in any direction, though they are gene-

Fig. 99.



Various forms of the conical compound papillæ, deprived of their epithelium:—*a*, *b*, and especially *c*, are the best marked, and were provided with the stiffest and longest epithelium; their simple papillæ are more accumulated. *d*, approaches the fungiform variety; *e*, *f*, come near the simple papillæ.—Magnified 20 diameters.

Fig. 100.

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 2 diameters.

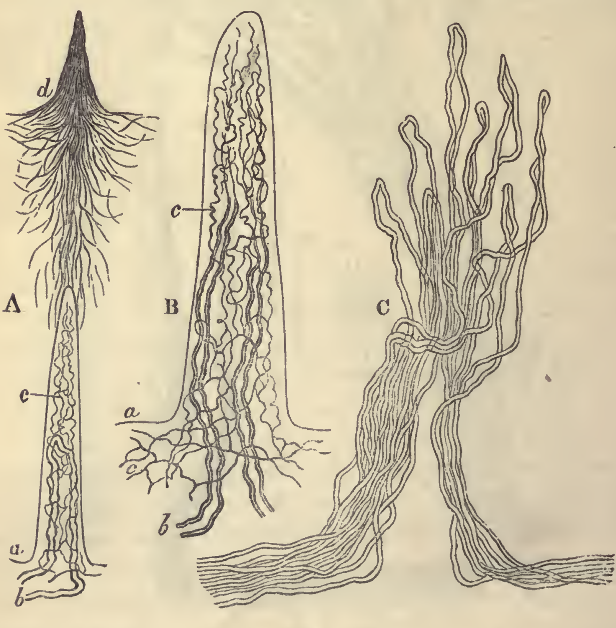
B. Filiform compound papillæ:—*a*. Artery. *v*. Vein. *c*. Capillary loops of the secondary papillæ. *b*. Line of basement membrane. *d*. Secondary papillæ, deprived of *e*, *e*, the epithelium. *f*. Hair-like processes of epithelium capping the simple papillæ.—Magnified 25 diameters. *g*. Separated particles of epithelium, magnified 300 diameters.

1, 2. Hairs found on the surface of the tongue. 3, 4, 5. Ends of hair-like epithelial processes, shewing varieties in the imbricated arrangement of the particles, but in all a coalescence of the particles towards the point. 5, encloses a soft hair.—Magnified 160 diameters.

rally inclined backwards. These epithelial processes are more stiff, according as the particles of which they consist approach more nearly to the dense texture of hair; and a few among them actually enclose minute hairs, pointed at the end, and provided in some cases with an extremely fine central canal. One of the largest of these we found $\frac{1}{10}$ of an inch long, and from $\frac{1}{2000}$ to $\frac{1}{3000}$ of an inch thick (fig. 100, 2). The others have an imbricated arrangement of the particles in various degrees, which will be understood without detailed description on reference to figure 100, 3, 4, 5. Many of them may be regarded as soft or uncondensed hairs, and preserve the same thickness for a considerable length.

The structure of the secondary papillæ, from which these hair-like processes pass off, differs somewhat from that of the simple papillæ in the situations previously described. This difference consists in their larger size and more pointed form, as well as in their greater stiffness

Fig. 101.



A. Secondary papilla of the conical class, treated with acetic acid:—*a*. Its basement membrane. *b*. Its nerve-tube forming a loop. *c*. Its curly elastic tissue. The epithelium in this instance is not abundant; but the vertical arrangement of its particles over the apex of the papilla is well seen, *d*, and illustrates the mode of formation of the hair-like processes described in the text—Mag. 160 diameters.

B. A similar papilla, deprived of its epithelium:—*a*. Basement membrane. *b*. Tubular fibre, probably forming a loop, but its arch not clearly seen. *c*, *c*. Elastic fibrous tissue at its base and in its interior.—Magnified 320 diameters.

C. Nerves of a compound papilla near the point of the tongue, in which their loop-like arrangement is distinctly seen.—Magnified 160 diameters.

and elasticity; the latter quality depending on the abundant yellow fibrous tissue they contain, and which, with a wavy, almost spiral character, has a general longitudinal direction (fig. 101, *c*, *c*, *c*). They are commonly found to contain tubular nerve-fibres, which we have on several occasions, but not always, seen to terminate in loops (fig. 101, A, B, C). We have usually found it easiest to distinguish the tubular fibres in the papillæ at the front of the tongue.

The reader will at once recognize the broad and obvious distinction between the papillæ last described and all the other varieties, and will probably surmise, on structural grounds, that they can scarcely share in the reception of impressions which depend on the contact of the sapid material with the papillary tissue. The comparative thickness of their protective covering, the stiffness and brush-like arrangement of their filamentary productions, their greater development in that portion of the dorsum of the tongue which is chiefly employed in the movements of mastication, all evince the subservience of these papillæ to the latter function rather than to that of taste; and it is evident that their isolation and partial mobility on one another must render the delicate touch with which they are endowed more available in directing the muscular actions of the organ. The almost manual dexterity of the organ in dealing with minute particles of food is probably provided for, as far as sensibility conduces to it, in the structure and arrangement of these papillæ.

The simple papillæ on the base of the tongue, and those clothing the circumvallate and fungiform papillæ, do not appear to differ from one another in any important structural condition, notwithstanding their variety of outward form and arrangement in the compound organs: their epithelium, though of the scaly kind, is very thin, and would easily permit the transudation of sapid substances dissolved in the mucus of the mouth. The softer and perhaps cellulated interior of these papillæ may have a further influence on the act of sensation. With regard to the use of the singular configuration of the circumvallate and fungiform papillæ, it may be conjectured that the fissures and recesses about their base are designed to arrest on their passage small portions of the fluids in which the sapid materials are dissolved, and thus to detain them in contact with the most sensitive parts of the gustatory membrane.

We may here allude to a certain gradation that is apparent from the papillæ of touch, through those of taste, to the absorbing villi of the small intestines. Touch shades into taste, and at a lower point sensibility is lost. In the tactile papillæ, the excitant of the nerves merely comes into contact with the exterior of a thick epidermic covering: in those of taste, the epithelium is permeated by the special excitant of the nerves; while the intestinal villi are still more elaborately and exclusively organized for absorption. Another class of papillæ might be here spoken of in conjunction with those of taste, as will be seen at a future page.

On the precise Seat of Taste.—Authors differ considerably on this subject: some limit it to the hinder part of the tongue, about the root and sides; some extend it more or less over the whole dorsal aspect and to the tip; others describe it as existing also on the soft palate; while Majendie is of opinion that the pharynx, gums, and teeth are likewise possessed of it. This contrariety, while it shews the difficulty of the subject, may be in some measure explained by the indefiniteness of tastes when faintly perceived by small portions of the surface, by the influence on taste of the commonly associated senses of touch and smell, by some diversities really existing in different individuals, and by the ambiguity necessarily attending experiments on special sensation among the lower animals. As the subject is interesting in its bearing on the question of the nerves of taste, we shall here briefly consider it.

Touch, as it exists in the tongue and other highly endowed parts, discovers to us not merely the presence and physical properties of bodies, but their actual position: we recognize the situation of the impression in reference to the whole organ, by virtue of a power common in a greater or less degree to all sensitive nerves (p. 403). Every one who has attended to the effect of sapid substances applied to small separate parts of the tongue must feel that a similar capacity of assigning the position of flavours accompanies the sensation of taste; and on this power in the nerves of taste, aided, as is usually the case, by the nerves of touch, we greatly rely for the determination of the question before us.

In the first place, all allow that acute taste resides at the base of the tongue, over a region, of which the circumvallate papillæ may be taken as the centre, and also on the sides near the base. These parts are supplied solely by the glossal twigs of the glosso-pharyngeal nerves.

Secondly, some writers, among whom are Valentin and Wagner, believe the middle and anterior parts of the dorsum of the tongue to be usually incapable of appreciating flavours; while numerous others hold the contrary opinion, with which our own careful and repeated experiments, on other persons as well as ourselves, quite accord. Sour, sweet, and bitter substances applied to the sides, and especially to the tip, of the protruded tongue, we find to be at once distinguished; though, when placed on the middle of the dorsal region, they make little or no impression till pressed against the roof of the mouth. In the latter case, however, the taste of sugar is sufficiently distinct, and referred definitely to the spot on which it is laid; so that its being tasted does not depend on its diffusion or removal from the central to the circumferential parts, as some imagine. The region now spoken of is supplied almost solely by the lingual branch of the fifth nerve, though Valentin has described a twig of the glosso-pharyngeal running on the under surface towards the tip.

We conclude generally, with regard to the tongue, that the whole dorsal surface possesses taste, but especially the circumferential parts, viz. the base, sides, and apex. These latter regions are most favourably situated for testing the sapid qualities of food; while they are much less exposed than the central part, to the pressure and friction occasioned by the muscles of the tongue during mastication. The central region, as a whole, is more strongly protected by its dense epithelium, and is rougher, to aid in the comminution and dispersion of the food.

Thirdly, the soft palate and its arches, with the surface of the tonsils, appear to be endowed with taste in various degrees in different individuals. Admirault and Guyat affirm that the sense is acute in a spot about the centre, above the uvula; and in some individuals it has so appeared to us. We have also found evidence of the existence of taste on the sides and arches of the soft palate in some individuals, but not on the pharynx, gums, or elsewhere. The soft palate and its arches are supplied by the posterior palatine branches of Meckel's ganglion, and sparingly by the glosso-pharyngeal nerves.

Of the Nerves of Taste.— Taste having been shewn to exist independently in parts supplied, on the one hand solely by the glosso-pharyngeal nerves, on the other solely by the lingual branches of the fifth pair, it follows, as a direct consequence, that these nerves must respectively participate in the sense; and there is besides reason to attribute a share to the palatal branches of the fifth. Amid many conflicting, and some quite irreconcileable statements on this disputed point, with which it would be needless to distract the reader's attention, the weight of evidence derived from other sources seems to be much in favour of the above conclusion.

The origin and connexions of the glosso-pharyngeal nerves, which will be described at a future page, may be referred to in connexion with this question. Rapp found no lingual branch of the fifth in the tongue of the swan or parrot, both of which have acute taste. The glosso-pharyngeal and par vagum supplied the organ.

Evidence from Experiments.— From observations on the effects of section of the glosso-pharyngeal nerves in dogs, Panizza, and, subsequently, Valentin and Wagner, concluded that taste was completely lost after their division, and, consequently, that these are the sole nerves of the sense. But in such an inquiry negative results have far less value than positive ones; and we therefore consider the experiments of Müller, Gurlt, and Kornfeld, and those of Alcock and Reid, who all agree that decided indications of taste remained after these nerves had been cut, as proving that the lingual branches of the fifth share in the sense. Müller, Gurlt, and Kornfeld, however, failing to find signs of taste after the lingual branches of the fifth were divided, concluded too hastily that these are the sole, or by far the principal nerves of the sense, in opposition to the experiments of Panizza and his followers, the positive evidence of which in this regard carries greater weight. The experiments of Dr. Alcock directly tend to reconcile these inconsistencies. He found that though taste remained after dividing the lingual branches of the fifth, yet it seemed completely lost in the anterior part of the tongue. Besides, it is not impossible that the rude injury inflicted in these contradictory experiments on either of the glosso-pharyngeal or the lingual branch of the fifth might temporarily deaden the sense of taste in the other, in a way somewhat similar to that, whatever it might be, in which loss of smell impairs taste. Valentin admits that one of the dogs in which he had cut the glosso-pharyngeal nerves was able to taste a fortnight afterwards; a period quite too short to have allowed reunion and restoration of function to the nerves, and making it likely that the sense had been only apparently, and not really lost.

Evidence from Disease.—In some cases loss of common sensation consequent on disease of the fifth nerve has been reported as being attended with loss of taste;* in others, taste appears to have been preserved:† on the other hand, taste has been sometimes lost while common sensation in the tongue remained.‡ We would interpret the apparently contradictory evidence of these cases by one which we have ourselves lately witnessed, and which will be found to accord remarkably with the foregoing views. A middle-aged man suffered for eight years from complete loss of sensation in all parts supplied by the fifth nerve on the left side, with the exception of the forehead. The left eye was lost by destructive inflammation: the tongue was quite without feeling on the left side. On experimenting on his sense

* Bishop, Med. Gaz. 1833; Romberg, Müller's Archiv. 1838, Heft iii.

† Noble, Med. Gaz. vol. xv. p. 120; Vogt, Müller's Archiv. 1840, p. 72.

‡ Noble, Med. Gaz. vol. xvi.

of taste, it was found to be clearly absent in the anterior and middle part of the affected side; but to be present behind, in the region supplied by the glosso-pharyngeal. He tasted acutely enough on the other side in front.

Blumenbach and others relate cases of congenital deficiency of the tongue, in which taste existed. These would show that taste resides in other parts of the mouth besides the tongue, if it were not very probable that a portion of the base of the organ with its gustatory papillæ, supplied by the glosso-pharyngeal nerves, existed in these individuals. Without accurate dissections of the parts, such instances throw little light on the question.

The tongue, as an organ of mastication, is provided with the sense of *touch*; the anterior portion, and especially the sides and tip, possessing this sense in an eminent degree. Division of the lingual branches of the fifth nerves in animals is attended with evidence of severe pain, and is immediately followed by loss of sensation in the front part of the organ; while cases of disease of the fifth nerve in the human subject are marked by loss of sensation in the tongue, in common with the other parts which the nerve supplies. The experiments of Alcock and Reid further shew, that mechanical irritation of the glosso-pharyngeal nerve in animals is accompanied with manifest pain. Hence there can be no doubt that the lingual branches of the fifth pair are the chief nerves of touch to the tongue, while the glosso-pharyngeal nerves furnish the feeble common sensation existing in its hinder part.

Conditions of Taste.—Taste may be produced by a mechanical or chemical excitation of its nerves. Dr. Baly has observed that a smart tap with the fingers on the tip of the tongue causes a taste sometimes acid, sometimes saline, which lasts several seconds: and galvanism acts in a similar way. Any tasteless substance pressed upon the base of the tongue occasions a bitter sensation, and, if prolonged, a feeling of nausea. These phenomena shew that the sensation of taste follows excitation of its nerves, however produced: and analogous ones have been observed in connexion with the other sensitive nerves. But sapid substances cause taste only when dissolved and made to permeate the tissue of the papillæ, so as to come into contact with their nerves. This is proved by the fact that no insoluble substance admits of being tasted, and constitutes a broad distinction between taste and touch; which in some respects approach each other very nearly, particularly in regard to the effects of strong chemical agents on their respective nerves, producing a harsh, pungent, burning *taste* or *feel*. Taste, like touch, is much influenced by the extent of surface acted on; and it is also heightened by the motion and moderate pressure of the substance upon the gustatory membrane. By the latter movements, the mucus and outer layers of the epithelium are removed, and the sapid material is brought into closer contact with the papillæ. The act of swallowing seems further necessary to the perfect appreciation of flavours. This is partly explained by considering how much the concurrent exercise of smell exalts the sense of taste. Most sapid substances, though in different degrees, affect the nose through the throat on being swallowed; and we are thus led to attribute to taste much of what is in reality due to smell. The nurse's device of holding the nose of the child in giving it disagreeable medicine, though commonly said to deaden taste, seems rather serviceable by excluding smell. Thus tested, taste is a less acute and definite sensation than most persons imagine. Nevertheless, the difficulty of discriminating between the two senses indicates a real, though obscure, alliance between them, rendered closer by habit and association.

The impression of cold air deadens the sense of taste, and has, we believe, been the source of some of the discordance in the recorded results of experiments. Cold acts similarly on touch.

Do Taste and Touch co-exist in any of the Papillæ? — A papillary structure is, essentially, an arrangement for increasing the surface by which a membrane may have contact with external substances; and, while the analogy with the skin leaves no doubt that this structure in the tongue is concerned in the exquisite touch enjoyed by the organ, it is almost as certain that it is also concerned in taste. The question then arises whether touch and taste reside in the same papillæ or in distinct ones.

Now it is possible, as far as we know, that nerve-fibres of different endowments may be associated in the same papillæ, and therefore that one and the same papilla may possess both capacities. Taste, however, it is evident, demands a more delicate external apparatus in connexion with its nerves than touch; so that touch might be exercised with an apparatus adapted to taste, though not in all cases the reverse. As far, therefore, as regards the simple papillæ at the base of the tongue, and those covering the circumvallate and fungiform varieties, it seems impossible, in our ignorance of any anatomical distinction between the nerve-fibres of the two endowments, to decide whether the two senses are or are not resident together in the same papillæ. But there are good grounds for supposing that the conical or filiform papillæ are not designed for taste. They are most largely developed in a part of the tongue where taste is feeblest, and are there intermixed with a number of fungiform papillæ sufficient to account for the little that exists. Their structure and position, as already remarked, lead to the same conclusion. It may be added, that, in the lion, where these papillæ are capped with spines, so thick and rigid as totally to incapacitate them for taste, they are furnished at the base with an additional tuft of soft secondary papillæ, that seem specially adapted for the latter function. It is possible that certain soft papillæ, which we have frequently seen springing up about the base of the less developed filiform ones in the human tongue, may contribute, in a similar manner, to the sense of taste.

Are the Varieties of Taste referrible to the Varieties of the Papillæ? —It has been imagined that the differences of form met with in the papillæ might be in some special relation to the leading varieties of tastes, as the bitter, sweet, sour, etc.; but the careful experiments of Horn on this interesting point can scarcely be considered as tending to establish such a correspondence. The difficulties, however, of experimenting are so great, that neither can they be said to disprove it: for a considerable extent of impression is necessary to ensure a perception sufficiently definite to be relied on; and the different papillæ are for the most part too much intermingled to admit of several of a similar kind being tested apart from others. The most that can be deduced from Horn's observations is, that more than three-fourths of the substance he applied to the circumvallate papillæ, including, we suppose, the simple papillæ we have described on the neighbouring surface, excited a bitter taste, or one in which a bitter was associated with some other, especially an alkaline or saline flavour; and that on the region where the filiform papillæ abound the majority of substances tasted acid, or acid with a mixture of bitter or sweet. In regard to the fungiform variety no decided results were obtained. These facts will perhaps help to explain the effect of the act of swallowing in modifying and heightening flavours, since the food is much more completely brought into contact with the papillæ on the base of the tongue during that act.

After-tastes.—Impressions of taste remain longer than those of the other senses, because the fluids exciting them must of necessity continue for some time in contact with the nerves after having saturated the intervening papillary investment. For the same reason it is difficult to say how much of the taste that lingers after the substance has apparently left the mouth is due to the excitation of the nerves by particles still remaining in the papillæ, and how much to that state of the nerves, which, in all the senses, prolongs the perception, after the mere excitation has ceased. The taste left in the mouth by many substances is, however, very different from that which they produce in the first instance. Horn has remarked that this *after-taste* is usually bitter; while, with one of the most bitter substances known, viz., tannin, it is sweet. This circumstance appears to shew something in taste corresponding to the complementary colours in vision, and seems dependent on a state of the nerves which, for want of a better word, may be termed one of exhaustion, consequent on their previous stimulation. It will illustrate the cause of many familiar phenomena of taste; such as the effect some flavours have in exalting, modifying, or destroying our appreciation of others. Repeated over-stimulation of the nerves by the same substance exhausts their excitability by that or similar substances for some time afterwards.

There also appear to be relations between certain varieties of taste, which, though not classified or described by philosophers, are instinctively perceived, and constitute the foundation of the art of cookery. Attention and study given to the perceptions of this sense greatly enhance their delicacy.

Little is known of the subjective phenomena of taste, or those dependant on excitation of the nervous apparatus of the sense by internal causes. The various tastes which are experienced in disease are probably occasioned by depraved secretions in the mouth acting as foreign substances on the papillæ. The epithelium of the tongue, it is well known, is very prone to accumulate in the form of sordes, loaded with unnatural materials; on the removal of which, the natural taste is, in a great measure, restored. Majendie observed that dogs, after the injection of milk into their veins, licked their lips, and gave other signs of tasting. Such phenomena, if uniformly present, might be occasioned by the transudation of the fluid from the vessels to the nerves of the papillæ.

On the subject of taste we refer to the general treatises already cited; to Magendie's Physiology; Rudolphi's Physiology; Horn, über den Geschmacks-sinn des Menschen, Heidelberg, 1825; Panizza, Richerche Sperimentali sopra i Nervi, 1834, given by Dr. G. Burrowes in Med. Gaz. vol. xvi.; Dr. Alcock, Med. Gaz., Nov. 1836; Dr. Jno. Reid, Brit. and For. Med. Rev. vol. v. p. 309; Valentin, de funct. nerv. p. 116.

END OF THE FIRST VOLUME.