AN ESSAY

ON THE

CIRCULATION.

L. B. SEELEY AND SONS, WESTON GREEN, THAMES DITTON.

A CRITICAL AND EXPERIMENTAL ESSAY ON THE CIRCULATION OF THE BLOOD;

ESPECIALLY AS OBSERVED IN THE MINUTE AND CAPILLARY VESSELS OF THE BATRACHIA AND OF FISHES;

BY

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M.R.I. M.Z.S. &c. &c.

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AND WHITTAKER, TREACHER, AND ARNOT,
AVE MARIA LANE.
MDCCCXXXI.

TO

HENRY SMITH, ESQ.

MEMBER OF THE ROYAL COLLEGE OF SURGEONS.

My dear Sir,

There is no one to whom I can, with so much propriety, or so much pleasure, inscribe this little volume, as to you, who have aided me throughout the whole series of experiments which it details, with such talent and patience.

I must still make a further demand upon your kindness, and beg your assistance in my projected experiments upon *Respiration.* Notwithstanding the accuracy with which the changes induced in the atmospheric air by respiration, have been traced; their relative *quantities*, in different species, at different ages, and in different temperatures, have not been ascertained. I think it would yield some interesting results to compare these quantities, with the irritability of the muscular fibre on one hand, and with the tenacity of life on the other. I imagine they will be found to be inversely as these properties. This is an investigation beset with difficulties. But if these difficulties can be overcome, it is plain to me that one of the most important of the *Laws* of living beings will be established.

Accept my best thanks for your ready and able co-operation in these researches, and believe me to be,

My dear Sir,

Very faithfully yours,

MARSHALL HALL.

14 Manchester Square,
Oct. 12, 1831.

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Page 89, line 4, for 66, read 78.

PREFACE.

The comparative anatomist and physiologist will not ask why I have chosen the batrachian and fish tribes, for the investigation contained in the following pages.

It was necessary to select an animal which presented parts transparent enough to be seen perfectly under the microscope. The web of the frog is the only external part of an animal which affords the opportunity for such an inspection, for any considerable length of time.

It is well ascertained, that the lower the animal in the zoological scale, the more capable it is of submitting to division, and of yielding, in each part, the phenomena of life; until, in the lowest, each such part constitutes in itself a perfect animal.

The batrachia, as is well known to physiologists since the days of Spallanzani, admit of extraordinary mutilations without the immediate extinction of life. The wound made by the excision of the entire head in the salamander, has perfectly cicatrized, presenting an example of an acephalous living animal.[1] But such an animal is reduced, by this very mutilation, still lower in the scale ; and for this reason becomes capable even of further mutilation, without the immediate extinction of life.

It is, I believe, on this principle, that I have been enabled to remove the whole of the brain, medulla oblongata and medulla spinalis, in the frog, retaining the minute and capillary circulation ; an experiment which could not succeed in an animal of a higher order.

It will doubtless be incumbent upon us, to use much caution in extending the facts observed in the batrachia or in fishes, to animals higher in the scale. It will be necessary to exercise a just degree of reserve in passing from mere facts observed in one order of animals, to general conclusions in regard to others.

[1] M. Edwards sur les Agens Physiques, &c. p. 11.

The fact of the removal of the entire brain and spinal marrow, in the frog, without the immediate extinction of life, conjoined with the similar operation upon the chick in the egg, on the third day of incubation,[1] without interfering either with its life or developement, sufficiently establishes the independence of the circulation of the brain and spinal marrow, in a degree far beyond what is deducible from the experiments of Whytt or Spallanzani; of Dr. Philip or M. Flourens.

But the latter fact, together with that of fœtuses born perfectly grown without either brain or spinal marrow, seems to show that the functions of nutrition and of secretion are equally independent of the brain and spinal marrow. Is it not probable that, if, in the experiment of removing the brain and spinal marrow of a frog, a stream of air were continually directed into the cavities of the lungs, the animal would live indefinitely, the secretions being uninterrupted?

[1] "Si on ouvre un œuf de poule, de canard, ou de dinde, au troisième jour de l'incubation, on voit les mouvemens du cœur; si on détruit le cerveau et la moëlle épinière, le cœur continue à se mouvoir comme auparavant, l'incubation marche, et le fœtus continue ses développemens." Anatomie Comparée du Cerveau, par E. R. A. Serres; Tome II. p. 234.

No part of the brain or medullæ appears to be immediately necessary to the action of the heart. But the arterialization of the blood seems essential to secretion and nutrition. This change goes on in the chick without the act of respiration; and in the frog it is partially effected by the skin. It is possible that, in this latter case, we have but to support the respiration, to continue life, with the secretions, independently of the brain and spinal marrow.

It is a remarkable fact, observed in the web of the frog, that the minute nerves pursue a course close to the minute arteries. The terminal nerves and arteries may ultimately join and form the immediate secretory organ.

In every point of view the batrachia seem to offer the objects most likely to enable us to explore the connection of the large nervous masses with the heart, the minute and capillary circulation, and the secretory organs and processes.

In conclusion, I would observe, that there is not an experiment detailed in the following pages, which has not been repeated in the presence of some of the first physiologists of this country.

Before I conclude this short preface, I must introduce two postscripts to Chapter II.

P. S. 1. In the first place, I would observe that some further deductions may probably be drawn from the experiment of applying a ligature round the large vessels connected with the heart (described p. 78), beyond that of the irritability of the arteries.

After the power of the heart is thus excluded, what do we observe? A peculiar slow oscillatory movement of the blood in the arteries, whilst that in the capillaries and veins is motionless.

If the capillaries and veins have the same power of irritability as the arteries, why do we not observe the same phenomenon in them as in the arteries?

If the capillaries possess a muscular power, why is the blood all at once motionless in them, when the power of the heart is excluded? Must it not rather be inferred, that, as the blood contained in these vessels is without motion, the vessels themselves are without automatic power?

The same argument applies to the minute veins.

The blood continues to flow out of these vessels for a short time; it then remains motionless in them, unless impressed by some extraneous cause.

This experiment, carefully made, appears to me almost decisive of the question of the absence of irritability in the true capillaries. In order that it may succeed perfectly, it is essential that the animal should be vigorous, that the web should not be too tightly extended, and that no time should be lost in making the observations. If the circulation be feeble, or the web at all too tightly stretched, the circulation ceases entirely in all the series of vessels.

Any struggles on the part of the animal must be carefully observed, and their effects distinguished from those peculiar to the experiment.

The experiment of Haller and of Spallanzani consisted, not in the ligature, but in the division of the larger vessels. In such an experiment, the flow of blood is retrograde in the arteries, and thus the phenomena are complicated. The action of the heart is equally well excluded by a ligature, and the result is of a more simple and satisfactory character.

P. S. 2. In the second place I would remark, that the due diffusion of the blood in the minute and capillary vessels, appears to be regulated by a principle of tension subsisting between the contents of these vessels, their parietes, and the integuments.

It is on this principle that the blood leaves the vessels of the web as the powers of life decline.

It is on this principle that the blood flows into other channels when its proper channel is obstructed.

It is on this principle that the blood flows in all directions to the point at which a vessel is wounded or opened, as in the experiments of Haller and Spallanzani.

It is on this principle that there is an apparent circulation in the minute vessels after the excision of the heart, or the division of the large vessels of a limb. This movement of the blood is towards the point of division, and therefore retrograde in the arteries.

The effects of increased tension in the integuments are readily seen on extending the web more or less tightly: a feeble circulation is perfectly arrested, and the most powerful circulation is greatly modified, by this means.

This principle must never be forgotten in our experiments : otherwise we shall imagine we see the effects of irritability in vessels, when, in fact, we only see the phenomena resulting from tension; or we shall imagine we see the loss of irritability, when it is but the effect of obstruction, and the power of tension yielding to those of the circulation. The effect of a ligature applied to a vein, and the effect of those substances applied to the web, which induce stagnation by altering the state of the interior membrane of the vessels, are examples of the latter kind. In both cases, the tension of the vessels or integuments yields to the forces which propel the blood, and the vessels appear enlarged.

Incisions made through the membranes of the web or mesentery, always assume a circular or oval shape, by the operation of this tension and elasticity of these membranes, of which therefore there can be no donbt.

This tension of the integuments is, I think, the source of many of the phenomena of the minute and capillary circulation.

INTRODUCTION.

OF THE PRINCIPLES OF INVESTIGATION IN PHYSIOLOGY.

The sources of our knowledge in physiology, as in all natural science, are *observation* and *experiment:* the former consists in a sustained and watchful attention to events which pass under our eye in the ordinary course of nature; the latter, in devices for placing natural objects in new and unusual circumstances or situations.

Unhappily for the physiologist, the subjects of the principal department of his science, that of animal physiology, are sentient beings; and every experiment, every new or unusual situation of such a being, is necessarily attended by pain or suffering of a bodily or mental kind. Investigations in this science should, therefore, being exposed to peculiar difficulties, be regulated by peculiar laws. Otherwise, the physiologist will scarcely escape from the imputation of cruelty.

The *first principle* to be laid down for the prosecution of physiology is this: we should never have recourse to experiment, in cases in which observation can afford us the information required.

The various cases of monstrosity, and the interesting facts supplied by comparative anatomy, afford us ample scope for pure observation. They are a sort of natural experiment. And it appears to me that, in general, they present to us far less equivocal phenomena than any which can result from an actual operation involving the infliction of violence or of pain.

The physiological argument deducible from the facts observed in cases of monstrosity, was first clearly drawn by Mr. Lawrence [1] in this country, and afterwards by M. Lallemand [2] in France. The subject deserves still further attention, and will be repeatedly noticed in the following pages.

[1] Medico-Chirurgical Transactions, Vol. v. pp. 164—224. June, 1814.

[2] Observations Pathologiques; par E. Lallemand. Thèse soutenue le 6 Aout, 1818.

M. Geoffrey-Saint-Hilaire [1] has beautifully pourtrayed the anatomy of monstrosity. It still remains to elucidate its physiology in the same complete and philosophical manner.

It may be remarked also that comparative physiology has not kept pace with comparative anatomy. But the subject appears at present to be obtaining due attention. It will be seen in the course of this little work, how indispensable the knowledge of comparative anatomy is to the physiologist.

In addition to the sources of physiological discovery afforded by cases of monstrosity and by comparative anatomy, the various results of disease and of accidents afford us examples of undesigned experiments. M. Lallemand appears to me to have availed himself of these circumstances, as a physiologist, [2] more completely than any other observer. And here the eloquent expression of Celsus may be not inaptly quoted: "quæ cognosci in vivis possunt, in ipsis curationibus vulneratorum, paullò tardiùs, sed aliquanto mitiùs, usus ipse monstrabit." [3]

[1] Des Monstruosités Humaines.

[2] Observations Pathologiques.

[3] Præf. sub finem.

As a *second principle* of the prosecution of physiology, it must be assumed that no experiment should be performed without a distinct and definite object, and without the persuasion, after the maturest consideration, that that object will be attained by that experiment, in the form of a real and uncomplicated result.

It will be repeatedly observed during the course of the following pages, that it is one of the most difficult things in physiology, to devise an unequivocal and unexceptionable experiment. I fear most physiologists have erred in this point of view, and have regarded and detailed, as the simple effect of one particular cause, what was in reality the unsuspected result of another, or the complicated result of several.

Now an experiment made, in violation of the first of the principles just proposed, must be viewed as *unnecessary;* an experiment made in violation of the second, as *useless;* and both as *unjustifiable.*

Equally unjustifiable is the needless *repetition* of an experiment. This can only be proper where it is incumbent upon us to satisfy the requisitions of science, by removing a remaining source of uncertainty or error. To repeat a physiological experiment, in order to gratify the mere curiosity of individuals, appears to me to be inadmissible.

It must be admitted, as a *third principle* in physiological investigations, that we should not needlessly repeat experiments which have already been performed by physiologists of reputation. If a doubt respecting their accuracy, or the accuracy of the deductions drawn from them, arise, it then, indeed, becomes highly important that they should be corrected or confirmed by repetition. This principle implies the necessity of a due knowledge of what has been done by preceding physiologists. I shall rejoice if any thing brought forward in this little volume, shall induce my readers to pore over the works of Harvey; of Hunter, of Haller, of Spallanzani; of Whytt, of Legallois, of Dr Philip, of M. Flourens; of M. Edwards, &c.

Having, after due consideration of these principles, concluded that a given experiment is, at once, essential and adequate to the discovery of a truth, it must next be received as an axiom, or *fourth principle*, that it should be instituted with the least possible infliction of suffering.

In this point of view, Dr. Philip has the highest merit. That gentleman discovered that in many cases the newly-dead animal might be substituted for the living one, not only without disadvantage, but with the great advantage of at once avoiding the infliction of pain, and its effects in complicating the result of the experiment. In every possible instance, therefore, his experiments were made upon subjects incapable of feeling pain. It was, in fact, but taking the rabbit killed as for one purpose, and applying it to another and a higher one.

In all cases, the subject of experiment should be chosen from the lowest order of animals appropriate to our purpose, as the least sentient; whilst every device should be employed, compatible with the success of the experiment, for avoiding the infliction of pain. The batrachian reptiles are especially animals of this kind; and for many physiological purposes, they may be promptly deprived not only of sensation, but of motion, by a means which will be described in an early part of this Essay.

Lastly, it should be received as a *fifth principle*, that every physiological experiment should be performed under such circumstances as will secure a due observation and attestation of its results, and so obviate, as much as possible, the necessity for its repetition.

With these objects, physiological experiments should, if possible, only be instituted with the aid of competent witnesses. Sources of error will, in this manner, be detected, should they exist, whilst unequivocal truths will be duly authenticated. The necessary repetition of the experiment will be instituted, while its unnecessary repetition will be avoided.

In order fully to accomplish these objects, it would be desirable to form a society for physiological research. Each member should engage to assist the others. It should be competent to any member to propose a series of experiments, its modes, its objects. These should be first fully discussed,—purged from all sources of complication, prejudice, or error,—or rejected. If it be determined that such series of experiments be neither unnecessary nor useless, in the sense which I have attached to those terms, they should then be performed, repeated if necessary, and duly attested. Lastly, such experiments, with the deductions which may flow from them, may then be published with the inestimable advantage of authenticity.

Pursued in this manner, the science of physiology will be rescued from the charges of uncertainty and cruelty, and will be regarded by all men, at once as an important and essential branch of knowledge and scientific research.

This appears to me to be true, when the object of investigation is merely to acquire knowledge, although we may not foresee its future application to any useful purpose; how much more so when its application is obvious beforehand! I will suppose the case of drowning: whether our object be the restoration to life of a fellow-creature taken out of the water in a state of suspended animation; or the rescue from death of another fellow-creature under a criminal prosecution for supposed murder, I cannot imagine that an experimental investigation to determine the surest means of restoration in the first case, or the evidence of accidental or forcible death in the second, can for one moment be deemed otherwise than absolutely incumbent upon us. And if such a case be so imperative upon us, where shall we draw the line of distinction between it and others?

The whole science of medicine and surgery, indeed, is dependent on physiology. To exclude physiological investigation, would be to erect an utter barrier to the progress of our art, viewed in any other light than as mere empiricism. They alone can repair a machine who understand its construction and its movements.

In thus stating the argument in regard to what is right and just in physiological investigation, I have steered a course equally distinct from the heartless cruelties practiced by some soi-disant physiologists, and the senseless declamations of others against what they are pleased to call vivisections. The whole argument may be concentrated to a point:—are Harvey, Haller and Hale, worthy of our applause for their researches into the circulation, and the action of the heart? Let us remember that they performed experiments. It is not, therefore, to experiments that we can object, but to such experiments as are unnecessary or useless, or performed without regard to the pain or sufferings inflicted. We may at the same time admire the conduct of one experimentalist and condemn that of another.

Having ascertained any fact or facts, they should in my opinion, in accordance with a *sixth principle*, be laid before the public in the simplest, plainest terms. Controversy can be of little service to science. If there be a difference of opinion, let us adopt the advice of Celsus:—"Quum hæc per multa volumina, perque magnæ contentionis disputationes, a medicis sæpè tractata sint atque tractentur, subjiciendum quæ proxima vero videri possint; quod in plurimis contentionibus deprehendere licet, *sine ambitione verum scrutantibus;* perinde ut in hac ipsa re."[1]

In quoting the opinion of other authors, I think it should always be in their own words. I have uniformly observed this rule in the following pages. From the frequent misconstruction of the meaning of an author without this precaution, I would consider this as a *seventh* and final *principle* of treating physiology.

Such are the principles to be adopted in our investigations and disquisitions in physiology. If they be carefully observed, this science will be divested of the charges—hitherto not undeserved—of cruelty and of uncertainty; and its beauty and importance will be recognized together. What an anomaly it must appear hereafter, that, in the

[1] Præf.

early part of the nineteenth century, that department of physic which teacher the nature of the functions in the animal economy, was not recognized as an essential separate branch of the study of physic and surgery, in the schools of this metropolis !

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CHAPTER I.

OF THE ANATOMY OF THE MINUTE AND CAPILLARY VESSELS.

ALL the descriptions of the minute and capillary vessels and circulation which I have seen, contain so many inaccurate statements, that they appear to have been written from the imagination, rather than from actual observation. As examples of these inaccuracies, I may notice what is alleged of the frequent anastomosis or conjunction of the minute arteries, and of the immediate termination of those arteries in veins, as they are observed in the web of the frog. If such anastomoses and terminations of the minute arteries do really exist at all, their occurrence is so rare, that, after the most diligent search, I have not been able to detect a single instance of them. And, from the meagre and imperfect description given, and the imperfect microscopes employed, by the authors of these observations, I am persuaded that certain delusive appearances, which I shall have occasion to describe in the course of this paper, have been mistaken for these supposed phenomena in the distribution of the minute vessels.

The real course and distribution of the minute arteries and veins, and of the capillary vessels, and the real phenomena of the minute arterial, capillary, and venous circulation, are, on the other hand, so peculiar and interesting, that I think a detailed and faithful account of them cannot prove unacceptable to physiologists.

The point of greatest moment, in investigations of this kind, is, however, perfect accuracy. I have therefore taken the utmost pains to secure this object. I have employed the achromatic microscope of Mr. Dollond; I have devised peculiar modes of placing the moving scenes which I had to examine, under its object-glass; every fact has been equally and repeatedly witnessed by Mr.

Henry Smith, who has assisted me most kindly and ably, throughout the whole of this investigation; and the anatomy has been accurately given by the pencil of Mr. Hawkins.

It is essential, in the next place, in describing the minute and capillary vessels and circulation, that we should attach distinct ideas to the various terms employed. It is, especially, quite necessary to distinguish the capillary vessels from the minute arteries from which they arise, and the minute veins to which they give origin. From the want of attention to the terms employed, much confusion pervades the descriptions of those authors who have treated of this subject.

The minute vessels may be considered as arterial, as long as they continue to divide and subdivide into smaller and smaller branches. The minute veins are those vessels which gradually enlarge from the successive addition of smaller roots. The true capillary vessels are obviously distinct from each of these. They do not become smaller by subdivision, nor larger by conjunction; but they are characterized by continual and successive union and division, or anastomoses, whilst they retain a nearly uniform diameter.

These distinctions are highly important. Without them, the phenomena cannot be clearly described or understood. It is quite erroneous to speak of capillary arteries, or capillary veins, or of the true capillary vessels as a venous net-work,—as vessels containing a serous blood without globules, or as rather to be inferred than accurately seen. The last branches of the arterial system and the first roots of the venous, may be denominated minute; but the term capillary must be reserved and appropriated to designate vessels of a distinct character and order, and of an intermediate station, carrying red globules, and perfectly visible by means of the microscope. Meckel is obviously in error, in omitting to mention the capillaries altogether; and Adelon, in speaking of the capillary systems in the plural number, including under that designation the nutrient, secretory, and exhalent vessels.

Having made these preliminary remarks, I must revert to the plan devised for placing the moving blood in the field of the microscope to which I have alluded; for it is in this manner alone that the minute and capillary vessels can be traced.

It was a point of singular interest to ascertain whether there were any characteristic differences between the systemic and pulmonary minute and capillary vessels and circulation, and in the different parts of each of these. In order to institute the requisite comparison, in the same and in different animals, it was necessary that the lung and the mesentery should be placed under the microscope, and that the circulation should continue for a sufficient time unimpeded and undisturbed. The struggles of the animal during life, with the idea of its sufferings, would effectually have frustrated this object. It was, therefore, with no slight degree of satisfaction that I was enabled to devise a mode of annihilating the sensation and arresting the motions of the animal whilst the circulation was preserved entire.

The mode of proceeding to which I have alluded, is founded upon an interesting observation of M. Edwards,[1] that the batrachian reptiles, placed in water of 42° of the centigrade thermometer, or 108° of Fahrenheit, die almost immediately. It was an interesting point to ascertain the cause of so sudden an annihilation of life in these animals in such cir-

[1] De l' Influence des Agens Physiques sur la Vie; par M. F. Edwards, D. M. &c. 'A Paris, 1824.

cumstances; and in some experiments performed with the view of determining this point, I found that although sensation and motion had entirely ceased, and the animal had become rigid and apparently dead, the action of the heart still continued. It occurred to me at such a moment to place the lung of the animal under the object glass of the microscrope. I was highly gratified to find its circulation, arterial, capillary and venous, quite perfect! I had thus an opportunity of contemplating at leisure, in one instance during four successive hours, under circumstances free from the infliction of pain or suffering, this most splendid and interesting scene.

I have subsequently found that water of the temperature of 120°. of Fahr. answers far better than water at 108°. The batrachia plunged into water of 120°. die to sensation and motion almost instantaneously.

The salamander and the toad are the batrachia which are most to be preferred for this experiment. The lung of the former is most easily maintained distended, and displays the most simple circulation. The toad is far more tenacious of vascular life, and displays the beautiful phenomena of the circulation for a much greater length of time. The lung of the frog is very apt to collapse. It is necessary, therefore, to adopt another device when we wish to watch the pulmonary circulation in this species: the lung must first be moderately distended with air, by means of the blowpipe inserted into the larynx; the larynx must then be secured by a ligature. It is equally necessary to avoid too great distention of the lung, and all stricture upon its root as it passes out of the orifice made into the body of the animal; for then the circulation will be much impaired, or even totally arrested.

I. Of the minute and capillary vessels of the systemic circulation.

It is always perfectly obvious that the distribution of the vessels is strictly appropriate to the peculiar office, which they have to perform in each individual part or organ. The anatomy, as Mr. Charles Bell has so well-pointed out, constantly suggests the physiology; and in no case is this remark more distinctly verified, than in the peculiarities of the minute and capillary parts of the vascular system. It is in the more hidden of nature's operations, that we frequently discover the most splendid instances of design in its Author.

The number and distribution of the minute and capillary vessels, is accurately proportioned and adapted to the object of the circulation. When the structure of the part is simple, and the object of the circulation is its nutrition merely, the vessels are few in number ; when the part is more complicated, or other objects besides its nutrition are to be fulfilled, the number, character, and mode of distribution of the vessels, are appropriately modified.

1. *Of the minute and capillary vessels in the Fin and Tail of the Stickle-back ;—the Gasterosteus aculeatus of* LINNÆUS.

The fin and tail of the fish are merely natatory organs. Their structure, like their office, is simple, and the number and distribution of their minute and capillary vessels, are strictly in unison with their character. The rays have but one centre of movement, that at their origin ; and the texture which unites them, is merely, a reflex membrane. This part affords, therefore, an example of the simplest kind of the minute and capillary vessels and circulation.

The arteries run along each border of each ray, and pursue their course to its extremity. At the extremity of the ray, the artery is reflected, becomes venous, and pursues a similar but retrograde course along the outer side of the artery. The artery, during its whole course, and at its extremity, gives origin to capillary vessels, which are few in number, inclose large spaces, and at length join the veins.

Nearly at the point at which the ray divides into two smaller rays, the artery gives off a branch which crosses the ray, subdivides into two minuter branches, which run along the internal borders of these smaller rays respectively, at the termination of which they are reflected into veins, which, in their turn, unite, cross the ray, and join the principal vein. In this course, the artery gives off, and the vein receives a few capillary vessels.

Sometimes a minute arterial branch, or venous root, crosses the fine membrane between the rays, especially near the root of the tail; but in general, this membrane is endued with a few scattered capillary vessels only.

These various features of the minute and capillary vessels, in the tail of the Gasterosteus aculeatus, or stickle-back, are admirably pourtrayed in Plate I. I have briefly described them as they are seen in this species, in the first place, because it presents the simplest example, and consequently the type, of this interesting part of the circulation. The structure and circulation in the fin, are very similar to those of the tail.

2. *Of the minute and capillary vessels in the Web of the Frog;—the Rana temporaria of* LINNÆUS.

The structure of the foot of the frog is far more complicated than that of the fin or tail of the fish. Designed for leaping, and in some measure for apprehension, as well as for swimming, the toes are of the most complicated structure, and abundantly supplied with nervous, muscular, tendinous, ligamentous, and osseous textures. It is obvious that the minute and capillary vessels must be distributed appropriately. The circulation, like the part, is of a complicated character, and will require a more particular description and delineation than that of the fin or tail of the fish.

The larger arteries and veins of the frog's foot, run along the sides of the toes; the former give off, and the latter receive, about an equal number of branches and roots to and from the web.

The minute arteries are characterized and distinguished from the veins, by pursuing a straighter course, generally across the web, by being smaller in size, and lighter in colour, and by possessing a more rapid circulation. On these accounts they are apt to elude a cursory observation, and have been described as only half as numerous as the veins. The minute arteries and veins occur, in reality, as seen by a high magnifying power, in nearly equal numbers.

The minute veins are those vessels which, from being more visible, first strike the eye of the observer, on inspecting the circulation in the web of the frog placed under the microscope. They are tortuous, large, and red, and present the most distinct view of the flow of the blood.

The motion of the blood in the arteries, in the unimpeded circulation, is too rapid to admit of the globules being distinctly seen. In the veins, a single globule, or a number of globules, may be readily and distinctly traced in their motion along their varied course.

In the arteries, a pulsatory or accelerated movement of the blood is seen quite distinctly,—so distinctly indeed as to enable the observer to number the heart's beat with the utmost facility and accuracy. This pulsatory movement is not, in the unimpeded circulation, extended to the blood in the capillaries or veins. By a peculiar anatomy, which will be described shortly, the flow of the blood is made uniform at the very commencement of the former series of vessels.

In no instance have I been able to detect an anastomosis between the minute arteries. Such anastomoses between the roots of the veins are, however, not uncommon; and then a singular and interesting phenomenon is usually observed. The anastomosing roots which unite the two veins, present the curious fact of a double and contrary course in the flow of the blood: from some point or space, at which they are joined by one or more capillary vessels, the globules of blood are seen flowing in opposite directions into each of the two veins. If it be a point, there is an appearance of more crowded globules moving slightly in the form of a vortex; if a space, the globules move variously in it, and sometimes appear stagnant for a moment. It is also interesting to observe that, by the motions of the animal, or other causes which disturb the circulation, the globules of blood frequently pursue one course only in this anastomosing vessel; and this effect is permanent, if one of the veins with which it communicates, be permanently obstructed by a ligature or other means; that vein then presents the singular phenomena of giving off branches instead of receiving roots of smaller vessels, and of a retrograde course in the flow of the globules of blood. The anastomoses between the capillary vessels are exceedingly frequent indeed. The final object of this difference in the character of the arterial and venous branches and roots is very obvious. The circulation in the arteries is forcible and rapid, and not easily interrupted; anastomoses are not therefore required: the circulation in the veins, on the contrary, is slower and feebler, and far more easily suppressed by pressure or other accidents; if there were no anastomoses, the blood must then become stagnant, an event which is effectually prevented by the institution of a cross current from the anastomosing venous roots, and a retrograde current along one of the venous trunks: and thus the death of the part is prevented.

I have also sought in vain for any instance of the immediate termination of an artery in a vein. Generally, if not invariably, capillary vessels are interposed. Such terminations have been said to take place indeed; but I am persuaded that the appearance was delusive, and that, in reality, the artery crossed, unseen, instead of entering into the veins. This mistake is readily made: in the web of the frog, there are two distinct layers of vessels, one above the other, and it requires the most perfect microscope to detect the error which I have noticed, and such an instrument was probably not in the hands of the author of this observation.

The real mode of distribution of the minute arteries is extremely interesting; the precise mode of their transition into capillaries has not been described by any author.

The larger arteries first divide into branches. These subdivide into still smaller branches, which are also successively smaller than the trunk from which they proceed. At length the singular fact is observed, of each of the two branches being as large, or even larger, than the vessel from which they originate. At this point there is an obvious and remarkable change in the appearance of the circulation: the course of the blood becomes of only half its former velocity, and the globules, consequently, instead of moving too rapidly to be seen, become distinctly visible. If the vessel be traced, it is next observed, not to subdivide, but to unite with other branches, and to pass into that distinct system and net-work of vessels to which I would restrict and appropriate the term capillary. The object of this peculiar distinction and character of the capillary vessels is very obvious: a more diffused and slower circulation is required for administering to the nutrient vessels or functions, than that of the arteries; this peculiar character of the circulation is conferred at once, by the subdivision of the minute artery into branches of equal size with itself.

Such is the phenomenon of the transition of the arterial into the capillary vessels and circulation. I have examined it repeatedly with every power of the microscope. It is however by no means difficult to observe. And it becomes still more obvious if the circulation be impeded or languid. It is, indeed, by rendering the circulation slow, by means which will be described hereafter, that the fact of the transition of the minute arteries into true capillaries, is made most obvious. In the ordinary state of the circulation, the termination of the extreme minute artery is apt to be lost to view; and the change of rapidity in the circulation only adds to this obscurity by making the capillaries themselves more obvious.

This is not the only mode of transition from an arterial to a capillary vessel. Sometimes one of the branches only, in the case of subdivision, becomes capillary, whilst the other remains arterial, pursues its course and again subdivides variously; sometimes the artery becomes all at once singularly contorted, turning variously and giving origin to various capillary branches and the slower circulation.

The capillary vessels themselves are situated intermediately between the minute arteries and veins. They are in a certain sense cylindrical, that is, of uniform diameter throughout their course; and however frequently they may unite and divide and form anastomoses and even circles, they constantly retain the same size. The arteries and the veins viewed merely in their trunk and extreme branch, or origin, on the other hand, may be considered as cones, the former becoming gradually smaller, the latter, gradually larger, in their course.

The minute arteries then gradually divide and subdivide; the veins unite successively into larger and larger roots and trunks, and frequently anastomose; the capillaries unite, divide, reunite, and redivide, and anastomose continually, so as to form a complete net-work of vessels of uniform character and dimensions.

Plate II. represents the arrangement of the minute vessels. The comparative modes of distribution of the arteries and veins, and the frequent anastomosis of the latter are accurately copied.

Plate III. pourtrays the ultimate divisions of the minute arteries into their final branches, and of these into the true capillary vessels. The former are marked by continuous lines; the latter, by small circles arranged in the order of the vessels. The first arterial branch to the left, is seen to give off a single capillary vessel, to pursue its course for a short distance, and then finally to divide into two capillary vessels. The principal artery divides at its extremity into four extreme branches, and each of these into capillary vessels. The latter are traced variously joining and forming venous roots.

The double layer of capillaries is made very manifest by a simple device. Alcohol applied to the web of the frog was found speedily to induce a stagnant state of the blood in a certain portion of the capillary vessels, whilst it moved in the arteries and larger veins as before. I soon perceived that it was in the capillaries of that layer which was contiguous to the surface to which the alcohol was applied, that the circulation was interrupted.

Figure 2, represents a minute portion of the web seen in the microscope still more magnified, to the upper surface of which alcohol had been applied. The open lines are the upper layer of obstructed capillaries; the darker ones, the subjacent capillaries carrying on the circulation freely.

Figure 3, represents a portion of the web to the under side of which the alcohol had been applied. The stagnant and circulation vessels occupy an inverted position.

In order to view each series of capillaries distinctly, it is necessary to adjust the microscope so as to bring them severally into its focus.

The same device assists us also in distinguishing the arteries and larger veins from the true capillaries, the former remaining pervious after the latter are obstructed.

3. *Of the minute and capillary vessels in the Mesentery of the Toad;—the Rana Bufo of* LINNÆUS.

The distribution of the vessels in the mesentery is very peculiar. Nature's object is not merely to nourish this membrane, but to supply the intestines with blood. The mesentery is, therefore, chiefly the vehicle of an apparatus destined for an ulterior object; a few nutrient vessels only are distributed to the membrane itself.

On the first view of the circulation in the mesentery, we observe large arteries and veins, marked and distinguished by the directions of the fluid flowing through them, pursuing their course across the membrane. Occasionally a minute branch is given off by an artery, which divides and becomes capillary. The capillary vessels, like the respective membranes, resemble, in their mode of distribution, those of the fin and tail of the fish; they finally unite and form a minute venous root, which eventually joins a large vein.

In the mesentery, I have once distinctly observed the anastomosis of arteries. The contractions and peristaltic motion of the intestines probably interrupt the flow of the blood even through the arterial branches, and render such anastomoses necessary here, as would be superfluous in the web of the frog.

I have also seen the artery give off a minute branch, and this early to turn round and pursue a venous course. I have not determined whether such a vessel is a contorted artery, destined to divide and form capillaries and to nourish the root of the mesentery; or whether it really assumes the character of a vein, joining other veins.

The distribution of the vessels of the mesentery is given in Plate IV. The course of the large arteries and veins, and of the capillary vessels, is accurately marked. The former have an obvious destination and origin beyond the mesentery respectively; the latter are as obviously destined to carry nutriment to the membrane itself.

To this representation of the course of the minute and capillary vessels, in the mysentery, are added two sketches of the artery and vein of a frog; figures 2, and 3. Their object is to point out the singular distribution of maculæ or spots along these vessels.

These maculæ are similar to those of the skin, and if carefully traced, may lead to some conclusion as to the continuous character of the external integuments, and the vascular texture. Into this subject I have not had leisure to enter. It would, I doubt not, amply repay the trouble of the investigation, by some interesting results.

These maculæ also enable us to trace the course of the minute arteries and veins, and especially the former, when it would otherwise, from their empty state, be impossible. In this manner I have been able to ascertain a singular, but interesting anatomical fact, in regard to the relative situation and course of the minute vessels and nerves, which, after further research, I purpose to lay before the profession.

II. Of the minute and capillary vessels of the pulmonary circulation.

The character of the pulmonary circulation is, like its object, remarkably different from that of any part of the systemic circulation. As this object is the change induced upon the blood by its exposure to the influence of the atmospheric air, so the manifest design in the pulmonary structure, vessels, and circulation, is the diffusion of the blood over the greatest possible extent of surface.

1. *Of the Circulation in the Lung of the Salamander;—the Salamandre Crêtée of* Cuvier.

The lung of the salamander is simply vesicular ; the distribution of its minute vessels is equally distinguished by its simplicity, and by its beautiful symmetry and parallelism.

A large artery on one side of the lung, is exactly opposed to a large vein on the other. The artery gives origin to branches which are placed in an order perfectly parallel and symmetrical with the corresponding minute veins. These arterial branches sometimes divide into branches still smaller. When this is the case, it is always observed that venous roots, similar in form, still arise in parallel lines; whilst, on the other hand, when no such subdivision of the minute arterial branches takes place, the corresponding minute veins are equally destitute of these minuter roots, and run in a manner simply lineal and parallel with the artery.

We clearly discern the design of this arrangement. The final arterial branches and the venous origins are so placed, that the latter may most commodiously receive the capillary vessels into which the former ultimately issue, both being placed in parallel lines.

This may be said to be the principal mode of arrangement of the arteries and veins in the lung of the salamander: the large and minute branches and roots are placed in a state of parallelism. There is a second mode of arrangement, not less interesting to observe; some of the last branches of the artery, instead of being parallel with venous roots, pass into an angle or space, formed by the union of two such roots or by a flexure in the course of the minute vein itself.

Sometimes an arterial branch turns and crosses the main trunk, in order to place itself parallel with a venous root. Sometimes the minute branch of the artery divides itself into two extreme branches at a very obtuse angle, the lines of which are opposed to similar lines formed by venous roots equally uniting at an obtuse angle.

The whole of these arrangements are strictly represented in Plate V. The more the drawing is examined, the more remarkable and numerous will appear the instances of design displayed in the arrangement of the pulmonary vessels.

The object of this peculiar disposition of the minute arteries and veins of the lung is plainly that the capillary vessels into which the final branches of the former divide, may be received by the similar and similarly-disposed roots of the latter. The division of the minute arteries into capillaries, takes place at once, without any of those subdivisions observed in the arteries of the systemic circulation seen in the web of the frog. The arteries terminate, the capillaries begin and terminate, and the veins commence, equally abruptly. Between the final termination of the artery, and the commencement of the vein, there is a considerable space occupied by capillaries infinitely more numerous than those of the web of the frog, which diffuse the globules of blood over the intervening space, affording a sight of the most splendid description.

The final arteries give out, and the venous roots receive the capillaries not only at their points, but along their sides. This appears not to be the case with the larger vessels. Along the course of these in the dried lung there is a distinct space free from globules, plainly denoting that the blood is not directly received by them, but passes along or beyond them to ulterior minute venous roots; their course along or across the larger vessel is, indeed, sometimes quite obvious in the living animal, being marked by lines resembling the capillaries in form.

The minute and capillary vessels and circulation in the lung of the salamander, are the most distinct, from its purely vesicular structure, and the want of cells and vertical meshes which exist in the lung of the other batrachia. It may therefore be taken as affording the most distinct and perfect, because the most simple type of the pulmonary circulation.

There is plainly no disposition to anastomosis between the arteries, or to direct communication between the arteries and veins. There is uniformly an intermediate space; and this space is occupied by an intermediate set of vessels.

The final branches of the pulmonary arteries exist as rather large trunks, and then divide at once, both from their sides and extremities into innumerable capillary vessels. These like all other capillaries preserve one uniform size. They are far more numerous in proportion to the minute arteries and veins, and to the spaces over which they are spread than those of the systemic circulation.

On a cursory glance with a lens of moderate power, the pulmonary capillary circulation seems to be one uniform rush or flood of blood flowing with extreme rapidity in straight lines directly across the pulmonary membrane originating from a minute artery, diverging as rays from a point or line, as a centre, and converging in a similar manner to constitute a vein of similar form. The general idea conveyed is that of a splendid device for spreading the moving globules of blood over the greatest extent of surface possible.

It is only on employing a higher power that the frequent or rather continual anastomoses, junctions, and subdivisions of the capillary vessels become perfectly and fully visible. With such a power the minute arteries are seen to terminate abruptly in a net-work of capillary vessels, the communications of which are, as I have said, infinitely more frequent than those of the capillaries of the web. Along these vessels and their anastomoses, the globules of the blood are observed moving in every possible direction, spreading themselves over every point of the pulmonary membrane from a minute arterial branch or extremity, or converging in a similar manner to the point or sides of a minute vein, in a way quite peculiar to the pulmonary circulation. The capillary vessels of the lung appear to have a general course in a direct line from the minute artery, from which they arise, to the corresponding vein; but in this course they are really slightly tortuous, or waving, and retiform. It is altogether a scene very different from that of the involved and irregular tortuosities of the capillaries of the general circulation and will be best conceived on an inspection of Plate VIII., to which I shall have occasion to refer more particularly shortly.

If we institute a general comparison between the systemic and pulmonary circulation, we shall arrive at the following conclusions. The arteries in the former divide and subdivide at considerable intervals, until they become extremely minute; and from the rapidity of the circulation, are only distinctly seen by the aid of the higher powers of the microscope; in the latter, the subdivisions of the minute arteries take place at the nearest points along its course, the arteries terminate abruptly, the branches assume at once the capillary characters. The veins are formed in a manner perfectly similar to that of the division of the arteries, in the systemic and pulmonary circulation respectively: the capillary vessels of the systemic circulation are far less numerous and more tortuous than those of the lung. It may be said, that, in the web, the vessels are adapted to support the nutrition and life of its various textures; in the lung, that the membrane is a mere scaffolding to spread the vessels which convey the blood in the fullest manner over its extensive surface.

2. *Of the Circulation in the Lung of the Frog; the Rana temporaria of* LINNÆUS.

The lung of the frog is both vesicular and cellular. It is this last structure which renders the distribution of its vessels more complex and difficult to follow, than those of the lung of the salamander. The cells are formed by portions of membrane situated vertically and internally. The insertions of these membranes divide the external surface of the lung into meshes; the membranes themselves are constituted into vertical meshes by these mutual insertions.

Like the lung of the salamander, the lung of the frog is endowed with a large artery and vein. The course of these vessels is very peculiar. The former passes along the more convex side of the lung, along its surface; the latter, along the less convex side, and along the internal borders of the internal meshes. The larger branches of the artery pass to the right and left, and also occupy the surface of the lung; the larger veins pursue a similar course along the internal borders of the internal meshes.

This intricate relative disposition of external and internal meshes, and of the minute arteries and veins of the lung of the frog, renders it impossible to trace the course of the vessels far along its surface by the aid of the microscope; dipping down along the edges or centre of the perpendicular meshes, they necessarily pass out of the focus and elude our view.

The ultimate distribution of the minute arteries and of the minute veins is thus not easily traced; but it is obviously such as to admit most readily of the diffusion of the blood over the various meshes, external and internal, by the former, and of its reception by the latter. A minute artery is generally seen passing into the centre of each vertical mesh, whilst this mesh is bordered at its central edge by a minute vein.

The relative disposition of the large and minute arteries and veins, and of the external and internal meshes, is best seen by making a transverse section of the lung along lines equidistant from the principal artery and vein. Such a section afforded the opportunity for taking the sketches seen in Plates VI. and VII.

Plate VI. represents the artery pursuing its course along the external surface of the lung, or the external borders of the vertical meshes. Sometimes this course is a little obscured by the intervention of a mesh; it is then denoted by a dotted line.

With this plate, Plate VII. must be compared. It will then be seen that the large vein, the course of which is represented in it, occupies the other or internal borders of the vertical meshes, and is consequently never obscured by their intervention. In every part these veins were raised over the pencil point, before their position was transferred to the paper.

The minute arteries are frequently seen to terminate, and the minute veins to originate, in the central part of one of the meshes, always rather abruptly. The course of the larger arteries, and of some of the minute arteries is generally at the edges of the meshes. Occásionally, an artery or a vein is observed to traverse the angular part of a mesh. Whenever a minute artery is seen, whether terminating or pursuing its course, innumerable branches of an equal and uniform size are given off, which are at once capillaries; similar capillaries are seen to unite and form each minute vein. The scene is precisely the same; it is the course of the globules of the blood, to or from the vessel, which alone demonstrates the difference. A similar distribution of arterial, venous, and capillary vessels takes place over the surface of the vertical meshes, as is obvious from an oblique view of the membrane carefully dried so as to preserve the appearance of its vessels and of the globules of blood.

3. *Of the Circulation in the Lung of the Toad; —the Rana Bufo of* LINNÆUS.

The structure of the lung of the toad is very similar to that of the lung of the frog. The distribution of its larger vessels is, however, singularly different. The artery, as well as the vein, pursues its course along the internal or central borders of the vertical meshes.

The toad offers an advantage over the frog, as the subject of investigations into the nature of the pulmonary circulation. Its lung remains distended, without the application of a ligature to the larynx. And although sensation and motion have entirely ceased, the beat of the heart and even the circulation in the lung are perfect during many hours. It was on this account that this animal was chosen, in order that an accurate sketch might be taken of the pulmonary capillary circulation.

The pulmonary circulation was very vivid during four hours, in the case in which the sketch, Plate VIII., was taken. This sketch may therefore be considered as most accurate. The course of the blood in the capillaries is marked by arrows, so that the arteries and the veins can be readily distinguished.

It would not become me to speak of the merits of any performance of my own. But I believe I may say that there is not, in any published work, any accurate account of the minute and capillary vessels and circulation, or any account at all of the minute and capillary circulation of the lungs.

It is singular, that in the midst of the dispute concerning the irritability of the capillaries, there should be a doubt whether these vessels be real tubes or mere canals. There are many reasons which incline me to the latter opinion. It is a further point in minute anatomy, highly interesting and important, and deserving of the most assiduous research.

The terminal secerning and exhalent arteries, the absorbent and incipient veins, are still undescribed, still unknown. He who shall first trace them, will deserve the reward of approval, whether it be his good fortune to obtain it or not. I think the discovery will be made by means of the singular spots which accompany the arteries and veins.

The microscope will, I think, be the means of the next improvements in anatomy. The minute anatomy of the lower orders of animals, must be pursued by its aid. The organization, or want of organization of morbid structures, will be determined by its use.

Another object of inquiry in the same class, is that of the distribution of the minute and ultimate branches and origins of the nerves. The minute anatomy of the nerves, whether viewed alone or in conjunction with that of the arterial system, is one of the most interesting which can occupy the scientific physician.

CHAPTER II.

OF THE POWERS WHICH CIRCULATE THE BLOOD.

FROM the epoch in the history of physiological science, fixed by the brilliant discovery of Harvey, the circulation of the blood has continued to occupy the attention of physiologists.

The question of the entire circulation is a problem made up of so many elements, that it is not extraordinary that it should have been so difficult to fix and limit the value and influence of each; and as usual in the absence of proofs, the subject has been rendered still more obscure, by being veiled in a variety of conjectures.

The circle performed by the blood may be not inaptly divided into four arcs: of these the heart must be viewed as the principal and first;

the arteries as the second; the capillary vessels as the third; and the veins as the fourth. To view each arc distinctly, as well as the whole circle connectedly, will greatly assist us in forming accurate views of the nature of the circulation.

Galen, of whom Harvey speaks as "viri divini, patris medicorum," appears to have been the first to have a distinct view of the circulation,—the first to have reasoned correctly upon a view of part of the valvular structure of the heart. He uses the following words, which will be regarded as remarkable, considering the remote period at which they were written: "Est mutua anastomosis atque oscillorum apertio, arteriis simul cum venis; transumuntque ex sese pariter sanguinem et spiritum, per invisibiles quasdam atque augustas plane vias. Quod si os ipsum venæ arteriosæ itidem semper patuisset, nullamque natura invenisset machinam, quæ claudere ipsum, cum est tempestivum, ac rursus aperire queat; fieri nunquam potuisset ut per invisibilia atque exigua oscilla sanguis (contracto thorace) in arterias transumeretur: neque enim similiter omnis ex quovis attrahitur, neque emittitur. Sed quemadmodum quod leve est, facilius eo quod gravius, dilatatis instrumentis, attrahitur, iisdem autem contractis exprimitur : ita et per latam viam celerius aliquid quam per angustam trahitur, ac rursus emittitur. Cum autem thorax contrahitur, pulsæ atque intro compressæ undique, quæ in pulmone sunt, venosæ arteriæ, exprimunt quidem quam celerrime, qui in ipsis est, spiritum; transumunt autem per subtilia illa oscilla sanguinis portionem aliquam ; quod nunquam accidisset profecto, si sanguis per maximum os (cujusmodi est venæ arteriosæ) ad cor retro remeare potuisset. Nunc vero reditu per os magnum intercluso, dum comprimitur undique, distillat quidpiam in arterias per exigua illa orificia."[1] "Nisi valvulæ essent, triplex sequeretur incommodum, ut sanguis ipse frustra longum hoc curriculum subinde emetiatur; in diastolis quidem pulmonis adfluens, et quæ in ipso sunt venas omnes referciens ; in systolis vero, quasi æstus quidem maritimus instar Euripi, motum identidem huc atque illuc reciprocans, qui haudquaquam sanguini conveniat."[2]

But to Harvey is due the honor of having clearly demonstrated the entire circulation; and the no less honor of having set us an early

[1] Galen de Usu Partium, Lib. vi. Cap. x. [2] Ibid.

example of philosophical investigation and induction, almost free from fault or deficiency to this very day. The treatise "De Motu Sanguinis" of Harvey should be in the hands of all our students.

I cannot refrain from the pleasure of enriching my little volume with the following interesting recapitulation of Harvey's argument for the circulation, although rather long: "Quoniam multos video hærere, et de circulatione dubitare, et aliquos oppugnare, eo quod me non penitus intellexerunt; eorum gratia, breviter, quid dictum velim in libello de cordis et sanguinis motu, recapitulabo. Sanguis in venis contentus, suo quasi fundo, ubi copiosissimus (in vena scilicet cava, juxta cordis basin et auriculam dextram) sensim, ab interno suo calore incalescens et attenuatus, turget, attollitur, fermentantium in modum; unde auricula dilatata, sua facultate pulsifica se contrahens; propellit sæpius et confestim in dextrum cordis ventriculum; qui, impletus, sua systole subsequenter sese, illo impulsu, sanguine expediens (cum egressum valvulæ tricuspides impediunt), in venam arteriosam (qua patens porta datur) compellit; quo illius distensionem facit.

In vasis arteriosis, jam sanguis adversus valvulas sigmoides recurrere impotens: simulque, inspiratione et exspiratione, extenti et ampliati et restricti pulmones, et una quoque vasa ipsorum, huic sanguini viam transitumque in arteriam venosam præbent: ex quibus auricula sinistra (simul et pariter cum auricula dextra, motum, rhythmum, ordinem et functionem peragens) eundem, in sinistrum pariter ventriculum, sanguinem intromittit, quem dextra in dextrum: unde sinister ventriculus simul et pariter cum dextro (quando regressus unde venerat propter eadem valvularum renitentium impedimenta prohibetur) in capacitatem aortæ et consequenter in omnes arteriæ ramos impellit: arteriæ hoc subitaneo impulsu repletæ, cum non ita subito sese exonerare possint, distenduntur, impelluntur, et diastolen patiuntur. Unde, cum continue et continenter idem reïteretur, colligo arterias, tum in pulmonibus, tum per universum, tot ictibus cordis et impulsionibus sanguinis adeo tandem distentas et infarctas fore, ut vel cessaret omnino impulsus, vel disrumperentur, vel dilatarentur, adeo ut omnem massam sanguinis a venis exhaustam continerent, nisi alicubi effluente sanguine exonerarentur.

"Idem quinetiam de cordis ventriculis ratiocinium, repletis et, ab auriculis, infarctis sanguine. Nisi pariter sese deplerent arteriæ, tandem ad extremum distensi ventriculi, ab omni motu destituti, fixique, permanerent. Atque hæc collectio mea demonstrativa et vera est et necessaria, si vera sint præmissa: illa autem vera esse vel falsa, sensus nos facere debet certiores, non ratio; αὐτοψία, non mentis agitatio.

"Sanguinem præterea in venis assevero semper et ubique de minoribus in majora currere, et versus cor ab omnibus particulis properare: unde colligo, quam copiam (continue intromissam) arteriæ receperunt per venas traditam, reverti tandem, eoque refluere unde primum pelleretur; et eo modo circuitu sanguinem moveri, fluxu et refluxu a corde per impulsum, cujus impetu per omnes arteriarum fibras cogitur: postea, ab omnibus partibus, continuato fluxu, regredi per venas successive, quibus absorptus et exhaustus traducitur. Hæc vera esse docet sensus ipse; et a sensibilibus collectio necessaria omnem dubitandi ansam tollit. Denique hoc est quod enarrare et patefacere, per observationes et experimenta, conabar: non ex causis et principiis probabilibus demonstrare, sed per sensum et experientiam confirmatum reddere, anatomico more, tanquam majori auctoritate, volui.

"Ex his notandum, quam vim et violentiam concitatamque vehementiam, in corde et arteriis majoribus, tactu et visu percipimus: pulsusque systolen et diastolen (in animalibus majoribus calidioribus) non dico, in omnibus vasis sanguinem continentibus, eandem esse, neque omnibus sanguineis animalibus; sed talem et tantam in omnibus, ut exinde fluxus sanguinis et citatior cursus, par arterias exiles, partium porositates, venarumque omnium ramos, necessario fiat; et exinde circulatio.

"Nam neque exiles arteriæ, neque venæ, pulsant; sed duntaxat majores et cordi viciniores pulsant arteriæ, eo quod non ita subito emittunt, ac impellitur sanguis. Nam experiri poteris, dissecta arteria et pleno gurgite exsiliente sanguine, ita ut libere exeat prout immittitur. In arteria illa, per quam transit, vix pulsum persentias; quia, data porta, transcurrit sanguis, non distendit. In piscibus, serpentibus, frigidioribusque animalibus, cor tarde et debiliter pulsat, ut vix in arteriis pulsum percipias, sanguinemque transmittit lento admodum gradu. Unde in his, ut etiam minoribus arteriarum fibris in homine, nulla tunicarum aut sanguinis distinctio; quia sanguinis impulsu non percelluntur.

"Rescissam et apertam arteriam (ut dixi) pertransiens sanguis non impellit, neque pulsat; unde clare cernitur arterias neque innata facultate pulsifica, neque a corde demandata, sed solo sanguinis impulsu, diastolen pati: nam tum, pleno ipso in fluxu longius profluente, tam systolen quandam, quam diastolen, discernere et tactu percipere poteris, ut antea dixi, omnesque pulsationis cordis differentias, rhythmum quinetiam et ordinem, vehementiam, intermissionemque in emanante fluore (sicut in speculo imaginem) evidenter agnoscere. Quemadmodum cum aqua, vi et impulsu siphonis, per fistulas plumbeas in altum cogitur, singulas compressiones instrumenti (per multa licet stadia distantia) in ipso aquæ exeuntis fluxu, singulorum ictuum ordinem, principium, incrementum, finem, vehementiam, observare et distinguere possumus; ita ex abscissæ arteriæ orificio. Ubi notandum, ut, in exemplo aquæ, continuum effluxum esse, licet modo longius exsiliat, modo propius; ita in arteriis, præter sanguinis concussionem, pulsum, vel vibrationem (quæ non in omnibus æque cernitur), continuum exinde fluorem motumque fieri, usquequo primum sanguis (auricula nempe dextra), ubi incepit, regreditur.

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But it is to Spallanzani and his translator M. Tourdes, that we are chiefly indebted for the state of opinion respecting the powers which move the blood, prevalent at that period.

Spallanzani observes:—" Quoique Haller pense que les effets de la systole du cœur ne s'étendent point jusqu'au système veineux, il est néanmoins persuadé, contre le sentiment de plusieurs auteurs, que la circulation du sang dépend entièrement ou en très-grande partie de l'action de ce viscère."

" Mes expériences me paraissent établir cette vérité d'une manière si frappante, que j'espère en convaincre le lecteur le plus sévère. Je vais d'abord démontrer l'insuffisance des causes qu'on voudrait associer à la puissance du cœur: elles sont plus ou moins nombreuses suivant l'opinion des physiologistes.

" Les uns ont recours à la contraction des artères; les autres à l'attraction des vaisseaux capillaires; d'autres à une force *vibratile* ou *oscillatoire* des parois vasculaires, produite par le stimulus du sang ; quelques-uns enfin prétendent que l'air contenu dans les artères et les veines raréfié par la chaleur du sang, seconde puissamment l'activité du cœur."

"On ne peut nier que l'hypothèse de l'attraction et de la force oscillatoire ne soit très-ingénieuse : mais si les vaisseaux éprouvaient les effets de ces deux puissances, c'est-à-dire une alternative de contraction et de dilatation, et une accélération de vîtesse, l'un et l'autre phénomènes devraient être sensibles ; néanmoins le résultat de *toutes mes observations* établit une parfaite immobilité dans les parois des rameaux capillaires, et un retard plutôt qu'une augmentation de vélocité dans le fluide qui s'y meut.

"Le témoignage des yeux nous apprend ensuite que le cours du sang est indépendant de la contraction des artères, puisqu'elle n'est visible chez plusieurs animaux que dans les plus gros troncs, et que dans ceux qui viennent de naître, et dont la circulation est apparente, on n'apperçoit aucun indice de systole et de diastole dans tout le systême des vaisseaux. L'insuffisance de ces théories démontrée, il est facile de prouver que la circulation du sang dépend uniquement de l'action du cœur.

Telle est d'abord la conséquence qu'il faut déduire du mouvement accéléré dans les veines, toutes les fois que ce viscère se contracte, car cette accélération ne peut avoir lieu sans que la force du cœur ne se propage jusqu'au fluide veineux, et ne lui imprime, ainsi qu'a l'artériel, la vîtesse donc l'un et l'autre jouissent."

"Le cœur cesse-t-il de battre ? la circulation s'arrête à l'instant même ; reprend-il son mouvement ? elle se ranime de suite ; et si l'on suspend ou renouvelle l'action de ce muscle, le sang discontinue ou recouvre sa vîtesse ordinaire.

"Les pulsations du cœur sont-elles enfin moins fréquentes ? le sang coule avec plus de lenteur ; il devient même immobile sur la fin de la systole, et son mouvement ne recommence qu'avec la contraction suivante. Il serait sans doute difficile de prouver avec plus d'évidence que le cœur est le seul et unique mobile de la circulation du sang.

"Un autre fait digne de remarque, c'est qu'au moment où le cœur cesse de battre, le fluide veineux s'arrête avant l'artériel, et qu'après le rétablissement de l'activité du cœur, la circulation commence dans les artères plutôt que dans les veines. L'explication de ces deux phénomènes ne saurait être plus simple: les veines reçoivent après les artères l'impulsion du cœur, et sont les premières à perdre le mouvement qu'elles en ont reçu. Ajoutez à ce fait l'accélération du fluide veineux qui disparaît avec la cause qui la produit, c'est-a-dire, avec la systole du cœur."[1]

The translator of Spallanzani makes the following remarks upon this interesting paragraph:—"Telle est la force des préjugés et des hypothèses, qu'ils aveuglent souvent les personnes les plus capables d'en reconnaître l'erreur et la nullité. Spallanzani, qui s'est assuré par les expériences les plus directes et les plus positives, que le cours du sang s'exécute avec vîtesse et régularité dans des vaisseaux séparés du cœur par une ligature ou par une section, que la circulation se maintient dans l'universalité des artères et des veines, plusieurs heures, et même des jours entiers, après la destruction de ce viscère, croit néanmoins que le cœur est le seul et unique mobile du mouvement du sang. Je ne pourrais mieux réfuter cette étrange opinion de notre professeur, qu'en rapportant les expériences contenues dans la

[1] Expériences sur la Circulation; par Spallanzani. Ouvrage traduit par J. Tourdes. Paris, pp. 261—266.

"Idem quinetiam de cordis ventriculis ratiocinium, repletis et, ab auriculis, infarctis sanguine. Nisi pariter sese deplerent arteriæ, tandem ad extremum distensi ventriculi, ab omni motu destituti, fixique, permanerent. Atque hæc collectio mea demonstrativa et vera est et necessaria, si vera sint præmissa: illa autem vera esse vel falsa, sensus nos facere debet certiores, non ratio; αὐτοψία, non mentis agitatio.

"Sanguinem præterea in venis assevero semper et ubique de minoribus in majora currere, et versus cor ab omnibus particulis properare: unde colligo, quam copiam (continue intromissam) arteriæ receperunt per venas traditam, reverti tandem, eoque refluere unde primum pelleretur; et eo modo circuitu sanguinem moveri, fluxu et refluxu a corde per impulsum, cujus impetu per omnes arteriarum fibras cogitur: postea, ab omnibus partibus, continuato fluxu, regredi per venas successive, quibus absorptus et exhaustus traducitur. Hæc vera esse docet sensus ipse; et a sensibilibus collectio necessaria omnem dubitandi ansam tollit. Denique hoc est quod enarrare et patefacere, per observationes et experimenta, conabar: non ex causis et principiis probabilibus demonstrare, sed per sensum et experientiam confirmatum reddere, anatomico more, tanquam majori auctoritate, volui.

"Ex his notandum, quam vim et violentiam concitatamque vehementiam, in corde et arteriis majoribus, tactu et visu percipimus: pulsusque systolen et diastolen (in animalibus majoribus calidioribus) non dico, in omnibus vasis sanguinem continentibus, eandem esse, neque omnibus sanguineis animalibus; sed talem et tantam in omnibus, ut exinde fluxus sanguinis et citatior cursus, par arterias exiles, partium porositates, venarumque omnium ramos, necessario fiat; et exinde circulatio.

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humours within proper bounds. I think indeed this very pressure doth not a little contribute to keep on the circulation of the blood.—For as the whole body is continually compressed by the incumbent atmosphere, it must force the blood through the veins towards the heart, seeing it cannot run back by a retrograde motion into the arteries on account of the valves, that are found up and down in the veins. So little indeed of the original motion, impressed by the heart on the blood, remains in the larger veins, that it would scarce mount from the feet to the heart, unless to preserve, as it were, an equilibrium in the veins and arteries, which, being contiguous, form a kind of inverted syphon, whose legs are of equal altitude. So slow truly is the progress of the blood in the veins of the limbs, that many valves are placed in them to take off the weight of the superincumbent blood, lest it should slide back towards the extremities. It seems therefore by its mere motion in the veins not capable of overcoming the constrictive power of the heart and forcing into the ventricle, so as sufficiently to dilate it.—The perpetual pressure therefore of the atmosphere adds to the momentum of the blood, acting as a kind of antagonist against the innate and strongly constrictive power of the heart, which is more or less the natural faculty of every sphincter-muscle. For as soon as the lungs, expanded by inspiration, make room for the blood issuing out of the heart into the empty blood-vessels of the lungs (a kind of momentary vacuum being made in them by the expanse of the lungs) the heavy atmosphere, constantly compressing the whole habit of the body, forces as much blood into the right ventricle of the heart as it can well receive, whilst at the same time the elastic air, rushing through all the lungs and pressing on all its blood-vessels, adds no small degree of force to the very rapid currents of blood, which are observed to be here vastly much swifter than in any of the branches of the aorta; so that by this means the momentum of the blood is so much increased as to force into the left ventricle of the heart. But enough of this, as it is not my design in this little work to give a complete account of the circulation of the blood; I only would here by the way take notice, that the pressure of the atmosphere is one, out of many, and that too, not a contemptible one, of the causes of the circulation of the blood, and to hint at the same time how much the gravity of the air may promote, and its levity retard it."[1]

Haller and Hunter, and, indeed many other physiologists, observed the effect of inspiration and expiration upon the condition of the jugular and other large veins, the brain, &c. But to Dr. Barry is undoubtedly due the honor of having prosecuted the subject experimentally.

Having given this rapid sketch of the opinions of those physiologists who have chiefly occupied themselves in the investigation of the powers which move the blood, I shall now proceed to the detail of my own observations. It will speedily be perceived how much is to be discovered, by carefully observing one individual arc, of the powers which move the blood through the whole circle; and it will be seen how invaluable the batrachian and fish tribes are for this purpose.

1. *Of the Extent of the Influence of the Heart in the Circulation.*

If the circulation in the web of the frog be carefully examined under the most favourable circumstances, it will be seen to be very rapid in the

[1] On the Air and Epidemic Diseases. Preface, pp. ix—xii.

arteries, much less so in the capillary vessels and in the veins; and equable in all.

I have very seldom, however, if ever, seen the circulation so perfect as not to be able to detect with a good microscope, a degree of pulsatory acceleration of the blood in the arteries at each contraction of the heart. Judging from my own observations entirely, indeed, I should have stated that the natural circulation was rapid and slightly pulsatory in the minute arteries, and slow but equable in the capillary and venous systems.

If the circulation be, on the other hand, in the slightest degree impeded, the pulsatory movement, at each systole of the heart, becomes very manifest. It is seen in all the three systems of vessels, arterial, capillary, and venous. In the arteries there is generally an alternate more and less rapid flow of the globules, at each systole and diastole of the heart; in the capillaries and veins, the blood is often completely arrested during the diastole, and again propelled by a pulsatory movement, during the systole of that organ. In other cases a pulsatory movement is seen in the arteries only, the blood in the capillaries and veins moving slowly but equably.

It is impossible to observe these phenomena attentively without being persuaded that the power and influence of the heart, extend through the arteries to the capillaries, and through these to the veins.

The experiment is made in the easiest manner. A ligature being applied, in the gentlest way, round the limb of the frog, the circulation is immediately impeded in the web, so as to render the phenomena which I have described quite apparent. The pulsatory, and the retarded or arrested movements, of the globules of blood, may be varied, in an infinite manner, by increasing or diminishing the degree of tightness of the ligature.

The conviction rests upon the mind that the pulsatory power of the heart is capable of moving the blood through the arteries, the capillary vessels, and the veins, even in the extreme parts of the system.

2. *Evidence of the Muscular Action of the Arteries.*

The fact of a perfect circulation in acardiac fœtuses and acardiac animals, seems strongly to indicate an important influence in the arteries. It is difficult to conceive of this phenomenon, as accomplished otherwise than by the agency of these vessels. Still it may be contended that much in this acardiac circulation is effected by the capillaries.

The circulation in fishes and the crustacea, also leads to similar conjectures relative to the powers of the circulation of the blood. The former tribe have a simple pulmonic heart only, which sends the blood through the branchiæ, whence it is returned through vessels which, without any fresh accession of power, unite, form the aorta, distribute the blood to the remotest parts of the system, and issue in capillaries, and these in veins, by which it is finally returned to the heart. In the latter tribe of animals, there is, on the contrary, but a single aortic heart. This organ propels the blood through the systemic capillaries, through the venous system, and finally through the branchial capillaries and veins, until the circle is completed. Such at least must be our view of these phenomena, unless we discover that the power of the heart is aided by that of the arteries, or of the capillary vessels.

To these arguments from cases of monstrosity and from comparative anatomy, must be added that from experiment. Both Haller [1] and Spallanzani [2] performed the experiment of the excision of the heart, observing the subsequent condition of the circulation. Their account of this experiment is, however, in my opinion, very unsatisfactory. I resolved, therefore, to repeat it carefully, carefully observing the results. This I did thrice.

A ligature was applied round the aorta of a frog. The circulation in the web, which was previously very vigorous, was almost immediately arrested, first in the capillaries, then in the veins. In the arteries there was a singular oscillatory movement of the blood for ten or fifteen minutes. The globules of blood proceeded slowly onward for some seconds; there was then, all at once, a rapid retrograde movement of the blood apparently through the same space. This oscillation was repeated: the globules of blood were again moved alternately in progressive and retrograde directions as before.

It appeared to me that the artery gradually contracted, in successive portions, and slowly

[1] Deux Mémoires, &c. pp. 304—306.

[2] Expériences sur la Circulation, &c. p. 327, &c.

emptied itself by propelling the blood in a continued stream along its final branches: that it then dilated suddenly, and drew the globules of blood in a rapid retrograde course.

During the first contraction of the artery, the blood would be propelled along the capillaries and veins. During the succeeding contractions and relaxations of the artery, the globules would merely oscillate, being driven forwards and drawn backwards alternately.

From these observations, it would appear almost certain that the arteries possess a muscular contractile power.

Another argument for the contractile power of the arteries, arises from a view of their anatomical structure. The structure of the arteries has been so skilfully displayed, and the argument flowing from it so beautifully deduced, by Mr. Hunter, that I must refer to the well-known work of that extraordinary man for full and satisfactory information on this point.

A further argument for the contractile influence of the arteries is particularly noticed by Laënnec. Speaking of augmented impulse in particular arteries, he observes :—" Ce phénomène est un de ceux qui prouvent le mieux, contre l'opinion de quelques physiologistes, que les artères ont une action indépendante de celle du cœur," &c.[1]

Lastly, an argument for the muscularity of the arteries, flows from observing the effect of elevated temperatures upon these organic tubes. I had observed that the batrachia, on being exposed to water of 120°. of Fahrenheit, not only died almost instantly, but that the superficial muscles became rigidly contracted. I exposed the heart to the influence of water raised to this temperature. It immediately became small, pale, and rigid. It then occurred to me that this experiment might confirm or correct our views respecting the muscularity of the arteries, and of other textures of the body. A mere fibre of a longitudinal muscle was shortened and made rigid; a portion of membrane or nerve underwent no change. An artery and vein were now placed in the warm water: they lay previously nearly equally flaccid upon a portion of glass: the influence of the elevated temperature was immediately seen in the artery, which became rigid and cylindrical; the vein suffered no apparent

[1] De l'Auscultation Médiate. Ed. 3. Tome III. p. 359.

change. We have thus an important confirmation of the opinion, that the arteries are possessed of a muscular and consequently of a contractile tissue.

These experiments were made upon the different textures of batrachian reptiles. In them a temperature of 95°. of Fahrenheit, will induce permanent contraction of the muscular fibres. A higher temperature has, however, a similar effect upon the muscular textures of the mammalia. This subject will be treated more at length in a subsequent part of this little volume.

Still it must be confessed that none of these arguments are absolutely decisive. The facts afford no distinct proof of the muscular action of the arteries. The functions of these vessels are mingled in the cases of the acardiac fœtus and the acardiac animal, in the fish tribe and in the crustacea, with that of the capillaries; and, as we shall have occasion to repeat hereafter, unless we are enabled to separate these two orders of vessels, it is impossible that we should ascertain the function appropriate to each. The argument derived from the structure and the augmented action of the arteries, and the influence of an elevated temperature, is more distinct. The apparent effect of alternate contraction and relaxation of the artery after the ligature of the aorta, is certainly most powerful; indeed it scarcely admits of a remaining doubt of the structure and function of the arteries. Still it is important that this possible doubt should be removed. This is finally effected, I think, by the fact which I am about to detail.

3. *Description of an Artery in the Frog and Toad, which pulsates independently of the Heart.*

Whatever presumption there might be in the arguments and facts which have been laid before the reader, for the contractile influence of the arteries, we still wanted a direct proof of this process, until I discovered the interesting fact of an artery in the frog and toad, which pulsates distinctly, for a considerable time after the removal of the heart.

The artery to which I allude, is a branch from each of the arteries which in the frog and toad, after separating at a short distance from the heart, rejoin and form the aorta. Pursuing its course backwards and downwards, it passes under the transverse process of the third vertebra. It is here bound down. It is also very tortuous. When the viscera are removed, two pulsating points are distinctly seen at this part. On a minute examination, these pulsating points are found to be portions of cellular and muscular textures, above and below the transverse process just mentioned, moved by the contraction of a subjacent artery.

On removing these textures carefully, and on removing the skin from the back of the animal, the part along which the artery passes on emerging from beneath the transverse process, is sufficiently thin and transparent to admit of its being placed under the microscope. The artery is then plainly seen to pulsate, becoming straighter and paler at each contraction. The adjacent textures are moved at the same time, and the blood is frequently seen to oscillate in a branch of the same artery situated very near it.

The course of this artery is depicted in Plate IX. The transverse process of the third vertebra, is larger and more prominent than the rest. Just above it, is seen a pulsating point. Immediately below it, is seen another pulsating point; and in this latter part, the course of the artery, its straightened form and paler colour at each contraction, and the oscillating globules in the adjacent branch, are distinctly seen by the aid of the microscope. The drawing was taken from an injected preparation of this artery.

The frog or toad exposed, as has been described, p. 64, to water of 120°. Fahr. presents all these phenomena most distinctly.

In this fact we have the most, and, I may add, the only, indubitable proof of a contractile action in an artery.

It is interesting to contrast the appearance of automatic contraction in this artery, with that of dilatation, the effect of the impulse of blood sent from the heart, as seen in the principal pulmonary artery in the batrachia. Whilst the former becomes straighter and paler, the latter is rendered still more tortuous, and is still more distended with blood. Mr. Hunter justly observes, "arteries during their diastole, which arises from an increased quantity of blood being thrown into them, increase much more in length than width, being thrown into a serpentine course; therefore, instead of the term diastole, it should rather be called the elongated state."[1]

[1] On the Blood, &c. Ed. 1791, p. 175.

The arteries are, indeed, a second heart in an elongated form. Their function appears to be so perfectly performed in health, that all visible pulsation from their action is lost at their extreme branches. The blood is carried along at last by such gentle undulations, caught in their full force from the heart, but softened first by the elasticity, and then by the contraction of successive portions of the arteries, that its flow seems to become uniform. It is as the powers of the system languish, or when impediments to the action of the successive portions of the arteries exist, that the blood is seen to move in their minute branches in a pulsatory manner.

4. *Want of Proof of Irritability in the True Capillaries.*

It may now be asked, what presumption is there of muscular contractile power, or irritability, in the true capillaries?

The flow of blood through the capillaries appears, in every instance, to be effected and modified by powers impressed upon it, of a character extraneous to any action of these vessels themselves.

The influence of the contraction of the heart is quite obvious upon the motion of the blood in the capillary vessels, as I have already stated.

Not less is the various influence of the struggles of the animal, in retarding, or arresting the flow of blood in these vessels, or rendering it retrograde.

Any cause of contraction in the membranes forming the web itself, has also a remarkable influence upon the course of the blood in the veins and capillaries.

If the limb be bound with a tight ligature, the blood is rendered retrograde in its movement along the minute veins and the capillaries, by slight degrees of pressure made upon that part of the limb which intervenes between the ligature and the web. The blood is thus simply pressed out of the large vein of the limb in a retrograde course along its roots and the capillary vessels. Nothing can be more convincing than this simple experiment, that the circulation in the capillaries is completely under the influence of slight external impressions.

In attentively observing the circulation in the web of the frog, we frequently remark anastomosing branches between its veins. In these branches the course of the globules of blood varies at every moment, and in every possible manner: sometimes this course is from one vein into the other; sometimes it is retrograde from the second into the first; sometimes it pursues two opposite courses, from various intermediate points, into each of the two veins.

After observing this phenomenon attentively, we are prepared for detecting other similar phenomena in the capillaries themselves; and especially in those occupying spaces between two adjacent veins. Every kind of movement in the globules of blood may be observed in these vessels, the obvious and distinct result of forces impressed upon them, or of issues afforded them.

Still more singular phenomena are produced by arresting the course of the blood along a large vein. Such a vessel immediately assumes the character of an artery, apparently giving off branches, instead of receiving roots—the globules of blood pursuing a retrograde course.

In vain we seek for evidence of a power to contract and propel the blood, in any of these phenomena of the true capillary vessels. Where then is such evidence to be found?

Dr. Philip argues for a contractile power in the capillaries first, from an experiment in which the brain or spinal marrow was crushed: an effect was observed upon the circulation in the capillaries, similar to what is observed in the heart under similar circumstances; the capillary circulation, like the beat of the heart, was immediately arrested or impaired. But most conclusive objections are opposed to this experiment. 1. The influence of the heart itself is not removed. It is true Dr. Philip argues that the effect of the experiment in destroying the action of this organ, cannot influence its result, because to remove the heart altogether is said not immediately to change the condition of the circulation in the web of the frog. Dr. Philip's account of the experiment is as follows:—" The web of one of the hind legs of a frog was brought before the microscope and while Dr. Hastings observed the circulation, which was vigorous, the brain was crushed by the blow of a hammer. The vessels of the web instantly lost their power, the circulation ceasing; an effect which cannot arise, we have seen, from the ceasing of the action of the heart. In a short time, the blood again began to move, but with less force. This experiment was repeated with the same result."[1] Whether this argument be well founded, or not, I leave to the judgment of the reader, after he shall have perused the detail of the experiment of the removal of the heart, given page 66,—an experiment witnessed by at least four competent judges. 2. The influence of the arteries, which we have proved to possess a contractile power, was not separated from that of the capillaries, with regard to which the question remains to be determined. There is no circumstance in the experiment to determine which set of vessels, the arteries, the capillaries, or even the veins, were affected by the experiment. 3. The capillary circulation was also left subject to the influence of contraction in the whole muscular system. This is thrown into spasmodic action by the act of violence inflicted upon the nervous masses; by this action of the muscles, the veins are compressed, and the circulation in the capillaries is mechanically arrested. The result is one of the most complex and equivocal kind, and utterly incapable of determining the question of a muscular action in the capillary vessels themselves considered separately and distinctly.

[1] On the Vital Functions; p. 81.

Dr. Philip's second argument for a contractile power in the capillaries, is derived from observing the effect of the application of various irritating substances to the web upon the capillary circulation and vessels. But nothing can be more unsatisfactory than such an experiment. 1. The pain inflicted, accelerates the circulation ; 2. the struggles of the animal variously retard or arrest it ; 3. the action of the irritant upon the membranes of the web, upon the parietes of the vessels, and upon the contained blood, is various and complicated. It is impossible to determine whether the action of the capillaries themselves be augmented or diminished, or whether these vessels, admitting them to possess any vital contractile powers, be excited or debilitated, in so complicated an experiment.

It is, therefore, obvious that whilst every fact relative to the capillary circulation leads us to ascribe its various phenomena to forces impressed upon it from without, there is nothing of satisfactory evidence or argument for an automatic power in them.

5. *Of the Influence of the Acts of Inspiration and Expiration upon the Venous Circulation.*

I have already quoted the singularly interesting passage of Huxham, respecting the influence of atmospheric pressure during inspiration, upon the circulation or flow of blood along the veins.

Dr. Barry justly observes, " A vague unauthenticated notion, that the return of the black blood to the heart is, in some undefined way, *influenced* by suction, may be traced as far back as the time of Harvey. Haller, and many others also, noticed a marked coincidence between the inspiratory movements of the thorax in the warm-blooded mammalia, and the motion of their venous blood. But the mechanism was never pointed out, by which nature, in these animals, applies the mighty agency of atmospheric pressure to the veins, and connects, as cause and effect, the expansion of the chest with the afflux of the centripetal fluids to the heart. The experiments, therefore, that demonstrate this mechanism, and supply these important desiderata in physiology, must be entitled to the meed of novelty, along with whatever other merits they may possess."[1]

In fact it is not conjecture, but proof which is wanted in physiology. And in regard to the present question, I, who have never seen the experiment, prefer quoting the opinion of no mean authority, and eye-witness of Dr. Barry's experiments, to offering any remarks of my own. Laënnec himself observes:

"Témoin de plusieurs des expériences de M. Barry, je suis convaincu de l'exactitude de son opinion, quant à l'influence de la pression atmosphérique sur la circulation veineuse, influence à laquelle on n'avait fait jusqu'ici aucune attention. La découverte de M. le docteur Barry est, à mon avis, le complément le plus remarquable qu'ait encore reçu celle de son illustre compatriote Harvey."[2]

Dr. Philip opposes an experiment and an argument to the views of Dr. Barry. He first shews that the circulation will go on apparently quite perfectly when influence of inspiration, and consequently of atmospheric pressure is removed: as when the thorax of an animal is freely opened.

[1] Experimental Researches. Preface, p. xiv.
[2] De l'Auscultation Médiate. Ed. 3. Tome III. p. 36.

I confess I cannot see any force in this objection. The arteries would doubtless carry on the circulation without the aid of the heart, could a continual supply of blood be effected; a fact actually observed indeed in acardiac fœtuses and in acardiac animals. Should we say that the heart does not circulate the blood, because the blood can be circulated without its agency or influence? Dr. Philip then argues that the parietes of the veins are such as to collapse, and render the influence of inspiration and the pressure of the atmosphere of no avail. This is in the first place, to oppose a mere argument to an actual and well-attested experiment. In the second place, it is to leave out of the consideration, the peculiar situation of the veins relatively to other and adjacent textures, and the perpetual flow of blood into them from other powers of the circulation.

But it is not my present object to enter into this particular question. I seize the opportunity, rather, to record an interesting fact. It is this: frequently on first placing the web of a frog under the microscope, there is for some minutes no circulation. Afterwards, when the circulation is seen proceeding rapidly, it is frequently instantly arrested on pressing or even touching the animal.

This effect appears to arise from the influence of fear. It ceases when the frog has been some time in its new situation.

It occurred to me that this cessation of the circulation probably depended upon interrupted breathing with the action of the expiratory muscles. However this may be, it is easily produced, at any time, by making a moderate pressure upon the thorax.

In this manner, we observe the effect of the effort of expiration, actual expiration being prevented by the closure of the larynx. It seems to be the reverse of the experiment of Dr. Barry. Its influence extends to the extreme parts of the circulating system. The influence of inspiration, in Dr. Barry's experiment may do so too: but I confess I think it still remains to be determined, where the influence of inspiration and of the atmospheric pressure begins; or, in other words, how far it extends from the thorax itself.

6. *Of some Modifications in the Flow of the Blood along the Minute and Capillary Vessels.*

Under the influence of certain modifying causes, the flow of the blood along the minute arteries and veins, and capillary vessels, becomes variously pulsatory, oscillatory, retrograde or arrested, in one or other of the three series of vessels.

The least obstacle to the circulation induces an obvious pulsatory movement in the globules of the blood. The slightest pressure of a ligature gently bound round the limb; the slightest tension of the web in preparing it for being placed under the microscope; the slightest degree of dryness of the web, will occasion this appearance of pulsation. It would appear that the contraction of the successive portions of the artery was insufficient under these circumstances, to keep up the continuous stream of blood, which is the mark and criterion of the perfect circulation.

This pulsatory movement is either an alternate more and less rapid flow of the blood, or an alternation between motion and rest. The former indicates a less obstacle to the circulation than the latter.

The next phenomenon in the modified circulation is oscillation. This may be either slight, or quite extraordinary.

A slight degree of oscillation frequently follows the state of mere pulsation; or is observed as the powers of the circulation fail. The heart seems to propel the blood into the remote vessels, during its systole; during the diastole the motion of the blood is probably rendered retrograde by the elasticity and pressure of the parietes of the vessels or of the textures of the contiguous parts.

But the most extraordinary example of oscillatory motion in the globules of blood, is seen in the minute arteries, on the subtraction of the action of the heart, as in its ligature or excision. The globules flow along the minute artery quite continuously for many seconds,—probably during the contraction or systole of its successive portions; it is then suddenly and rapidly moved in a contrary direction in the same vessel,—probably by its diastole.

The struggles of the animal produce extraordinary effects upon the motion of the blood in the minute and capillary vessels. The globules in the capillaries are frequently quite stagnant;

the arteries frequently disappear suddenly; the blood in the veins moves slowly, irregularly, and frequently in a retrograde manner.

If a ligature be tied tightly round the limb, the circulation in the web is arrested. By the gentlest degrees of pressure on the limb, below the ligature, the blood may be made to stagnate, to retrograde, or to oscillate, in every possible way.

Similar appearances are produced, if the web of the frog be stretched, or allowed to become dry. The circulation is first enfeebled, and perhaps made pulsatory; then it becomes oscillatory and stagnant; lastly, some of the vessels disappear, whilst others retain globules of stagnant blood. In the former case the vessels are probably simply pressed upon by the drying web; in the latter, they suffer some change in their parietes, not sufficiently ascertained, but the object of a future investigation. The web frequently becomes altogether transparent and colourless.

The effect of loss of blood is very singular. To the naked eye the web appears pale. Under the microscope an occasional globule of blood is seen passing across the field along a semi-transparent channel.

The circulation in the three orders of vessels in the mesentery, is exceedingly uncertain, from the difficulty of keeping this membrane in precisely the same situation. The least variation in the degree of tension, produces changes in the velocity and direction of the motion of the blood. And it is impossible to avoid this: pins tear the membrane; the peristaltic movements of the intestine disturb it. By the mere act of placing or replacing the mesentery under the microscope, a circulation, or a modification of the circulation, is produced, which did not exist before.

At this moment I have the mesentery of a dead frog in the field of my microscope. By waiting a little time, all motion of the blood ceases. By altering the situation of the membrane, a various kind and degree of motion of the blood, which might be called a circulation, is produced.

In fact I have long ceased to place the slightest reliance upon the circulation as seen in the mesentery, in physiological experiments of any delicacy. The circulation of the web, on the other hand, is unequivocal under judicious management, the arrangement of the toes and of the membrane remaining accurately the same.

CHAPTER III.

ON THE INFLUENCE OF THE BRAIN AND SPINAL MARROW UPON THE CIRCULATION.

THIS question has long engaged the attention of physiologists. It particularly occupied the attention of Haller, his followers, and his opponents.

Spallanzani, Fontana, and Whytt, were amongst the first to submit the question to the test of experiment, by removing or irritating the brain or spinal marrow, and observing the effect upon the actions of the heart.

More recently, the question has been investigated experimentally by Legallois, Dr. Philip, Mr. Clift, M. Flourens, M. Brachet, &c.

In the subsequent account of the experiments of these various authors, and of my own, I shall confine myself to those which have been made upon the batrachia and upon fishes. The question of the circulation is admirably studied in these lower animals; and I purpose hereafter to discuss the subject of the vital functions more generally in animals of a higher order.

The following account of the experiment of removing or irritating the brain and spinal marrow, is that of Spallanzani:

"Exp. CV. J'ai piqué avec une aiguille la moëlle épinière d'une grenouille: cet animal a de suite éprouvé des convulsions si violentes, que je n'ai pu distinguer la circulation dans les vaisseaux mésentériques: mais elles se sont insensiblement appaisées, et j'ai alors apperçu que le sang conservait la vélocité ou le repos qu'il avait auparavant; en sorte que la piqûre ne produisait (à l'exception des convulsions) aucun dérangement dans le cours du sang.

"Exp. CVI. *Sur deux salamandres.* Ces deux animaux m'ont offert les mêmes phénomènes que la grenouille. Les convulsions ont d'abord produit quelques désordres dans la circulation; mais à peine avaient-elles cessé, que le sang reprenait son mouvement ordinaire.

"Exp. CVII. *Sur quatre grenouilles et quatre salamandres.* Au lieu de piquer la moëlle épinière, je l'ai divisée transversalement: les effets ont été les mêmes.

"Exp. CVIII. *Sur quatre salamandres et cinq grenouilles.* J'ai détruit en différens endroits la moëlle épinière, sans que les résultats aient été différens.

"Exp. CIX. *Sur trois salamandres et trois grenouilles.* On a successivement coupé les différens nerfs qui partent de la moëlle épinière: les parties dans lesquels ils se distribuaient, éprouvaient pendant quelques minutes une commotion violente, et le sang tantôt augmentait de vîtesse, tantôt rétrogradait ou oscillait: mais il reprenait son cours ordinaire, lorsque les convulsions avaient cessé.

"Exp. CX. *Sur trois grenouilles.* Il serpentait au milieu des chairs blanchâtres de la cuisse, un nombre considérable d'artères et de veines: le sang y circulait avec sa vîtesse ordinaire: j'ai coupé les nerfs cruraux: il s'est à l'instant manifesté des convulsions violentes qui se sont propagées jusqu'à l'extremité de la jambe; et j'ai perdu de vue le mouvement du sang; mais il n'a pas tardé à devenir sensible, et à reprendre sa première vélocité.

"Exp. CXI. Le cerveau des grenouilles se compose de deux lobes et de deux appendices, l'une antérieure, et l'autre postérieure : la première se prolonge vers le museau, la seconde forme le commencement de la moëlle alongée. On peut mettre à nud et même trancher en entier ce viscère, sans que l'animal cesse à l'instant de vivre. Différentes piqûres sur le cerveau d'une grenouille ont amené des convulsions générales, et la circulation a éprouvé dans les vaisseaux mésentériques, des désordres qui ont disparu avec la cause qui les avait fait naître.

"Exp. CXII. *Sur quatre grenouilles.* Deux grenouilles experimentées de la même manière que dans l'observation précédente, m'ont offert des phénomènes semblables. J'ai tranché le cerveau de deux autres, sans qu'aucune lésion aussi considérable ait produit des effets différens.

"Exp. CXIII. *Sur cinq salamandres.* Les piqûres et l'enlévement du cerveau ont occasioné dans la circulation des désordres, qui se sont terminés avec les convulsions des nerfs.

" Exp. CXIV. Ces expériences ne me semblaient point cependant suffisantes pour décider si l'irritation nerveuse était la cause des irrégularités qu'éprouvait la circulation. Elles pouvaient dépendre d'une agitation mécanique des parties, produite par l'action désordonnée des nerfs : ainsi une simple secousse dérange souvent le mouvement du sang. Pour détruire ce doute, j'ai fixé la queue et la tête de la grenouille, de la même manière que les tégumens, c'est à dire, avec des épingles. Les chairs ont néanmoins éprouvé une espèce de frémissement qui a influé sur le systême vasculaire : mais il est des vaisseaux qui, par leur position, sont à l'abri de cette réaction musculaire ; tels sont les mésentériques et les pulmonaires, dans lesquels le sang a continué son cours ordinaire, quoique j'eusse piqué et incisé à différentes reprises la moëlle de l'épine.

" Exp. CXV. *Sur trois salamandres.* Les résultats ont été conformes à ceux de l'expérience précédente.

" Exp. CXVI. *Sur trois salamandres.* Le sang n'a cessé de stagner dans une portion de l'artère pulmonaire, et de circuler par jets dans l'autre partie, malgré l'incision que j'avais pratiquée dans la moëlle épinière. Il en a été de même de la veine pulmonaire.

" Exp. CXVII. *Sur plusieurs salamandres.* Les lésions les plus graves du cerveau, la rescision même de ce viscère n'ont rien changé à la circulation dans les vaisseaux pulmonaires et mésentériques.

" Exp. CXVIII. *Sur deux salamandres.* J'ai enfoncé la pointe d'un stylet dans le canal de l'épine, et détruit presque toute sa substance pulpeuse, sans que le cours du sang se soit dérangé dans les vaisseaux des poumons et du mésentère.

" Exp. CXIX. *Sur plusieurs grenouilles.* J'ai répété avec un égal succès les expériences CXIV, CXVI, CXVIII."[1]

The subsequent short account of a similar experiment is taken from Fontana:

" Qu'on ouvre la poitrine à un animal à sang froid (cette expérience est sujette à moins d'incertitude dans ces animaux, que dans ceux à sang chaud, chez lesquels l'effet est cependant le même) et qu'on stimule de la manière qu'on voudra les nerfs qui vont au cœur; ce muscle n'accélérera

[1] Expériences sur la Circulation; ouvrage traduit par J. Tourdes. Paris. 8vo. pp. 338—343.

pas pour cela ses contractions s'il est en mouvement, ni ne reprendra ses mouvements s'il est en repos, quoiqu'il soit encore en état de se contracter au moindre choc qu'essuyent ses fibres. On aura beau insinuer de longues épingles dans le canal vertébral, déchirer la moëlle épinière, et le cerveau : Le cœur demeurera insensible à tout : Les nerfs qui vont au cœur ne sont donc en aucune manière les organes du mouvement de ce muscle, comme ils le sont certainement dans tous les autres muscles. Ils ne pourront donc jamais lui causer aucune altération sensible, quelles que soient les affections de l'animal. L'expérience est certaine, et la conséquence est directe.[a]"[1]

Dr. Whytt's experiments were published in the Edinburgh *Physical* Essays, but they are alluded to in his well-known work on Nervous Disorders[2] in the following express terms :—" The regular alternate contraction of the hearts of frogs, for five or six hours after decollation and the destruc-

" [a] Cette importante vérité a été démontrée par l'Auteur, dans son traité sur la Physique animale, Tome I. p. 92. publié en Italien à Florence, en 1775."

[1] Sur le Vénin de la Vipere; par M. Felix Fontaine. Florence, 1781, Tome II. p. 169.

[2] Second Edition; p. 7, note.

tion of the spinal marrow, and for half an hour after they are separated from their bodies, clearly proves that an influx of a fluid from the nerves into the muscles, is not necessary for their contraction: " &c. These experiments are so truly interesting that I should think my account of this subject incomplete without the following extract:

"Immediately after decollating a frog, I destroyed its spinal marrow, by pushing a small probe down through its spine, which occasioned strong convulsions of all the muscles, especially those of the inferior extremities. Ten minutes after this, I opened the thorax, and found the heart beating at the rate of 45 times in a minute. Sixteen minutes after decollation, it moved 40 times in a minute. After half an hour it made 36, and after fifty minutes only 30 pulsations in the minute, which were now also become very small and feeble.

"N. B. When I opened the thorax of another frog immediately after decollation and destroying its spinal marrow, I observed its heart beating at the rate of sixty in a minute, which is four or five pulsations less than I have generally seen the hearts of frogs make in that time, when their thorax was opened without decollation.

"At nine minutes past eleven in the forenoon, immediately after decollating another frog, I destroyed its spinal marrow with a red hot wire, which produced terrible convulsions in all the muscles, as in the last experiment. I opened the thorax of this frog thirty five minutes after decollation, and observed its heart beating 30 times in a minute. The contraction of the auricle regularly preceded that of the heart: the auricle was not near so much distended with blood, nor the heart so much swelled as in those frogs which had a solution of *opium* injected into their stomach and guts. At one o'clock (*viz.* an hour and fifty-one minutes after decollation) the heart of this frog made twenty pulsations in a minute. At half an hour past two, when the room was become warmer by the shining of the sun, it beat 25 times in a minute; and when placed in the sun-beams, it performed 31 contractions in that time. After this, I removed the frog to an east window, where it was exposed to a cool breeze; upon which the motion of his heart became slower, so that in a short time it only made 25 pulses in a minute. I then exposed it anew to the sun-beams, by which its motion was soon quickened, so that it beat 30 times in a minute.

"At twenty-five minutes past five in the evening, (*viz. six hours and sixteen minutes* after decollation and the destruction of its spinal marrow,) the auricle of this frog's heart, which was still filled with blood, contracted twelve times in a minute; but the heart itself lay without motion, was swelled and very red: however, when pricked with a pin, it performed two or three pulsations, and then remained at rest, till roused by a new *stimulus*. At thirty-five minutes past five, the heart seemed to be quite dead, but the auricle continued its motion; nay, at half an hour past eight, near three hours after the heart had been without motion, the auricle, which was very near as much filled with blood as when I first opened this frog, beat 11 or 12 times in the minute; its pulsations, however, were not now so regular as to time, as they had been before.

"Is it not probable, that the auricle of this frog's heart beat longer than usual, because it continued to the last, to be filled with blood; whereas, generally, the auricles of frog's hearts, which are opened after decollation and the destruction of their spinal marrow, expel, after some time, the blood which they contain, and acquire the appearance of a small pellucid bladder filled with air?"[1]

The investigation of the influence of the brain and spinal marrow seems to have been interrupted from the period at which these authors wrote, until that at which Legallois performed his experiments —experiments amongst the most remarkable of physiology.[2] Speaking of the source of the power of the heart, Legallois observes:

"C'est ce principe formé dans le cerveau et la moëlle épinière qui, sous le nom de *puissance nerveuse* et par l'intermédiaire des nerfs, anime tout le reste du corps, et préside à toutes les fonctions. Le cœur emprunte toutes ses forces de ce même principe, de même que les autres parties en empruntent le sentiment et le mouvement dont elles sont douées, avec cette différence que le cœur emprunte ses forces de tous les points de la moëlle sans exception, tandis que chaque partie du corps n'est animée que par une portion de cette moëlle (par celle dont elle reçoit ses nerfs); différence qui

[1] Edinburgh *Physical* Essays, Vol. II. pp. 282—285.

[2] These experiments obviously contain the germ of the extraordinary work of M. Flourens. See Œuvres de Legallois; Paris, 1824, pp. 142, 143.

peut servir à expliquer l'intensité des forces du cœur, et leur continuité non interrompue definis le moment de la conception jusqu'à la mort." [1]

But the following extract, taken from the Report of the Institute, relates more immediately to our present inquiry into the circulation in the batrachia.

"Nous terminerons cet exposé des expériences que M. Legallois a répétées devant nous, par celles sur les animaux à sang froid, et dont les résultats sont entièrement opposés à ceux qu'ont obtenus et qu'ont tant fait valoir les plus zélés partizans de Haller, et entre autres Fontana.[2] L'auteur a ouvert, d'une part, le crâne, et de l'autre, la poitrine d'une grenouille, et mis le cœur bien à découvert, puis il a fixé solidement l'animal;[3] et pendant qu'un de nous observait les mouvemens du cœur avec une montre à secondes, il détruisit le cerveau et toute la moëlle épinière, au moyen d'un stylet introduit par l'ouverture du crâne. A l'instant, les mouvemens du cœur se sont arrêtés; ils n'ont recommencé

[1] See Œuvres de Legallois, à Paris, 1824, pp. 143, 144.

[2] Mém. sur les parties sensib. et irritab. Tome III, pag. 231.—Traité sur le vénin de la vipère, etc. Florence, 1781. Tome II, pag. 169—171.

[3] Mém. sur les parties sensib. et irritab. Tome III. pag. 233.—Traité sur le vénin de la vipère, Tome II. pag. 171.

qu'au bout de quelques secondes, et leur rhythme n'était plus du tout le même ; ils étaient plus fréquens qu'avant la destruction de la moëlle. La même expérience faite sur cinq grenouilles, a constamment donné les mêmes résultats. Les mouvemens du cœur n'ont pas été suspendu le même nombre de secondes dans toutes, mais la suspension a toujours été très marquée ainsi que le changement de rhythme ; nous ajouterons que l'amputation des cuisses dans des grenouilles dont la moëlle venait d'être détruite, n'a point fourni de sang, et que les salamandres décapitées après une opération semblable, n'ont point saigné non plus ; tandis que, dans l'un et dans l'autre cas, il y avait hémorragie quand la moëlle épinière était intacte."[1]

Dr. Philip takes a totally different view of the subject. He contends that the difference of the effects observed in Legallois' experiments, between removing and destroying the brain and spinal marrow, arises entirely from the difference in the mode of operation or experiment. The brain was simply removed; the spinal marrow was destroyed or crushed. Dr. Philip proceeds to state that either

[1] See Legallois, Œuvres, à Paris, 1824. pp. 257—258.

the brain or spinal marrow may be removed, without diminishing the action of the heart; whereas if either be crushed, the action of the heart is immediately enfeebled.

The following is Dr. Philip's detail of his experiments, as far as they relate to the batrachia:

"The brain and spinal marrow of a frog were removed at the same time. On opening the thorax, the heart was found performing the circulation freely.

"It appears from these experiments that the action of the heart is as independent of every part of the spinal marrow as of the brain; consequently, that the opinion of M. Legallois, that it derives its power from that organ, and particularly from the cervical part of it, must be regarded as erroneous. The author will soon have occasion to consider the facts which led M. Legallois to this opinion; it will appear that they admit of a very different explanation. He is now to inquire, whether the action of the vessels of circulation is also independent of the brain and spinal marrow.

"A frog was killed suddenly by cutting off the head after a ligature had been applied round the neck to prevent loss of blood; much loss of blood immediately destroys the circulation in the extremities. The spinal marrow was then destroyed by a small wire. On bringing the web of one of the hind legs before the microscope, the author found the circulation in it vigorous for many minutes, and in all respects resembling that in the web of a healthy frog. This experiment was repeated with the same result.

"A frog was immediately killed by destroying the brain and spinal marrow by a small wire. After it had lain dead for several minutes, part of the web of one of the hind legs being brought before the microscope, the blood was seen circulating in it as rapidly as in the web of a healthy frog. In making such experiments it is necessary to be aware, that handling and stretching the web tends to impair the vigour of the circulation in it."

"It appears from these experiments that the vessels of circulation, like the heart, retain their power after the brain and spinal marrow are destroyed or removed."[1]

The results of Mr. Clift's experiments upon the carp, are similar.

[1] On the Vital Functions. Ed. 3. pp. 63—66.

The last author whom I shall quote is M. Flourens. His deductions from his experiments are expressed in the following terms:

"Ainsi donc, la circulation, soutenue par l'insuflation, survit, chez les animaux adultes, à la destruction totale du système nerveux, et, chez les animaux voisins de leur naissance, elle survit à cette déstruction, même sans le secours de l'insuflation. La circulation ne dépend donc ni immédiatement, ni instantanément, ni essentiellement de ce système.

"Mais sa dépendance, pour n'être qu'éloignée et consécutive, n'en est pas moins réelle.

"A mesure que la destruction du système nerveux s'opère, la circulation se concentre et s'affaiblit. D'abord, la circulation capillaire sous-cutanée s'éteint; puis celle des vaisseaux les plus excentriques; il ne reste bientôt plus que la circulation des troncs voisins du cœur.

"Le système nerveux concourt donc à l'énergie et à la durée de la circulation: car, à mesure qu'il se détruit, elle s'affaiblit; et au bout d'un certain tems qu'il est tout-a-fait détruit, elle est tout-a-fait éteinte.

"En second lieu, il concourt à cette énergie et a cette durée non seulement d'une manière générale et absolue, mais encore d'une manière spéciale et déterminée: car lorsqu'une région determinée du système nerveux est seule detruite c'est toujours dans les seules parties correspondantes à cette région que la circulation se montre surtout affaiblie. Il y a donc une influence générale, c'est-a-dire de tout le système sur toute la circulation ; et des influences locales et partielles des diverses régions de l'un sur les diverses régions de l'autre. Enfin, dans tous les cas, la destruction complète du systême nerveux affaiblit tellement l'ensemble de la circulation, que, quelque tems que la circulation vasculaire survive encore, la circulation capillaire sous-cutanée est toujours presque instantanément éteinte.

" Ce dernier point est remarquable: car il a porté quelques auteurs à regarder la circulation capillaire, ou comme absolument indépendante de la circulation générale, ou comme plus soumise qu'elle à l'action nerveuse, ou même comme exclusivement soumise à cette action: toutes suppositions qui ne reposent, je crois, que sur une simple apparence.

" La circulation capillaire n'est ni plus spécialement, ni plus radicalement, ni surtout exclusivement soumise à l'action nerveuse ; mais elle accuse et manifeste plutôt les effets de cette action, parceque, placée comme elle est à l'extrémité de la circulation vasculaire, la force d'impulsion centrale qui n'y parvient jamais qu'affaiblie, n'y parvient plus du tout dès qu'une cause quelconque l'affaiblit plus encore. C'est ainsi que le sang coule d'un jet continu saccadé dans la circulation vasculaire, tandis qu'il oscille et hésite dans la circulation capillaire ; c'est ainsi qu'il oscille dans la circulation vasculaire même, quand elle est pres de s'éteindre, et que cette circulation se rétrécit et se concentre de plus en plus à mesure qu'elle s'éteint.

" En résumé, le système nerveux influe sur la circulation ; il y influe par tout son ensemble ; il y influe par ses diverses régions ; c'est surtout par la circulation capillaire que ses moindres effets sur la circulation générale apparaissent.

" Mais quel que soit le concours du système nerveux dans la circulation, ce concours n'est point instantané, car ce système peut être détruit et la circulation survivre un certain tems encore ; ni immédiat, car comme chacun sait, un intermédiaire particulier, le grand-sympathique, s'interpose entre le système nerveux proprement dit et les organes circulatoires.

"La circulation ne dépend donc, encore un coup, du systéme nerveux que d'une manière médiate et consecutive; et ce n'est pas lui qui l'ordonne et la détermine, comme il ordonne et détermine le mécanisme des mouvemens de conservation que nous avons vus."[1]

M. Flourens, in a recent memoir, published in the Memoirs of the Institute, has stated it as his opinion, that the power of the heart and circulation is only impaired by the destruction of that part of the nervous system upon which respiration depends. This point will be discussed presently more particularly.

I. Of the Experiment of Removing the Brain and Spinal Marrow.

Having fully detailed, in the very words of their authors, the conclusions deduced by Legallois, Dr. Philip, and M. Flourens from their experiments,

[1] Du Système Nerveux; Paris, 1824: pp. 195—199.

I now procede to detail my own, interspersing such remarks as appear necessary to the elucidation of the subject.

It will be seen that whilst Legallois and Dr. Philip occupy the extremes in opinion on the subject of the influence of the spinal marrow upon the circulation, M. Flourens, has adopted views which are intermediate between these extremes, and that since the publication of his great work, he has arrived at other views on the subject.

1. *Of the Criteria of the Power of the Action of the Heart.*

Before we can proceed with this investigation, it is absolutely necessary to fix upon some criteria of the effect produced. Legallois judged of the power of the heart by the fulness of the carotids, and by the hæmorrhage observed on amputating a limb. Dr. Philip adopted similar modes of judgment, adding to them the observation of the circulation in the web of the frog. But it appears to me essential to observe the results of the experiment with greater minuteness.

In effect, the circulation first ceases in the extreme, and then in the proximate parts of the web; first in the capillaries and veins, and then in the arteries. It may still be seen in the lung, however, in which it ceases in the same order, in the distant parts and capillary vessels first, then in the larger arteries; at length the lung ceases to be moved by the power of the contraction of the heart. Even at this period, the apparent action of the heart itself is vigorous and regular, and continues so for a very considerable time.

Criteria of the power of the heart are thus afforded us, in the continuance of the circulation, first in the web, and next in the lung; and lastly in that of the beat of the heart itself.

But in some fish, especially the eel, we have a still more easy and accurate mode of judging of the power of the heart and circulation. We can readily examine, in succession, the extreme part of the tail, and the successive portions of the dorsal fin; and lastly the pectoral fin. As the powers of the heart and circulation fail, the motion of the blood is gradually lost in portions of the fin more and more adjacent to the heart.

But besides these modes of judging, we have another in the periods of time, at which these changes take place, compared with similar changes in similar animals not subjected to experiment; for instance, in eels simply removed from their own element.

2. *Of the Nature of the Action of the Heart after its Removal from the body.*

It will be plain from these observations that we cannot judge of the effect of removing the brain and spinal marrow by observing the beat of the heart alone. Yet I cannot agree with Legallois that the action of the heart under these circumstances, or when taken out of the body entirely, differs in any manner, except in feebleness, from its natural beat. The report of the Institute makes the following statement upon this subject:

"La circulation continue dans les acéphales et dans les animaux décapités, parceque les mouvemens du cœur ne dépendent pas du cerveau, ou du moins n'en dépendent que secondairement. Nous devons faire remarquer que ce dernier point, sur lequel M. Legallois a répandu tant de clarté, ne présente que confusion et qu' erreurs dans les auteurs de l' ancienne école hallérienne et dans ceux de la nouvelle. Aucun d'eux n' a distingué les mouvemens du cœur, qui out lieu après la décapitation, de ceux qu'on observe aprés l' excision de cet organe, ou aprés la destruction de la moëlle épinière ; et ils ont pensé que les uns et les autres seraient également capables d' entretenir la circulation. Mais ces mouvemens différent essentiellement entre eux. Ces derniers n' ont aucune force pour entretenir la circulation, ils sont absolument semblables aux foibles mouvemens qu'on peut exciter dans les autres muscles, pendant quelques temps après la mort. M. Legallois les désigne sous le nom de *mouvemens d'irritabilité* sans attacher, pour le moment, d'autre sens à ce terme, que d'exprimer des phénomènes cadavériques."[1]

Legallois repeats this observation in his beautiful essay on the heart, in the "Dictionnaire des Sciences Medicales."[2]

That this observation is unfounded, appears from the following facts. If instead of removing the heart alone, it be removed together with the other viscera, in the salamander or the toad previously rendered insensible, its beat is not only still observed to continue, but the circulation is

[1] Œuvres de Legallois, pp. 260, 261.

[2] Ibid, pp. 348, 370.

distinctly seen in the pulmonary minute and capillary vessels. A slight degree of this circulation is still seen, if a double ligature be carefully passed under the heart, and then separated and tied above and below this organ and the roots of the lungs. In this case every part is removed, except the heart and pulmonary vessels; so that it approaches as nearly as possible to the case of the removal of the heart alone. Yet the action of this organ is still such as to carry on, in a slight degree, and for a short period, the circulation of blood through the pulmonary artery and a few of the capillary vessels.

It may also be observed, that in the last experiment, scarcely any part of the nervous system remained; its masses were entirely removed, its filaments alone were left to influence the result of the experiment.

It must, I think, be concluded, that the suggestion of Legallois, made but in the spirit of system, must be regarded as unfounded, and that the action of the heart, as long as it continues at all, must be considered as the same, varying in power or degree only.

I think the actual circulation of the blood has not been before seen proceeding entirely independently of the ganglionic system.

3. *Of the Effect of removing the whole of the Brain and Spinal Marrow at once.*

Having thus prepared my readers by a detail of the opinions of former writers, and of the modes of judging of the condition of the powers of the circulation, for estimating the real import of the phenomena observed, I shall proceed to give a faithful account of a series of experiments which I have made upon the influence of cautiously removing the brain and spinal marrow.

The brain of a frog being removed, the circulation in the web was seen to proceed vigorously. A fine wire was then passed into the spinal canal, and the spinal marrow was destroyed; the circulation in the web was now feebler than before, and it became more and more languid, first at the extreme part of the web, and afterwards at the nearer points, until it ceased altogether. On exposing the heart, it was found beating with apparent vigour, fifty-two times in a minute. On observing the lung, the blood was seen moving freely in one large vessel, and slowly in one or two capillaries. The movement soon became a mere oscillation. In the mesentery there was a feeble circulation in the large vessels. The beat of the heart still continued an hour and a quarter from the time of the destruction of the spinal marrow.

The brain and spinal marrow of a frog were removed with the utmost precaution to avoid the effect of shock. The circulation in the web which had been most vigorous, was observed to become very gradually slower; it was lost in the capillaries in five minutes, in the veins in ten, and in the arteries in between fifteen and twenty. The whole of these changes were slow and progressive. Some interval elapsed before we examined the lung,—and its circulation had ceased. The heart still beat feebly thirty-six times in a minute. Scarcely any blood was lost.

A flat stilet was introduced and passed through the brain and spinal marrow of a frog, at various times, until the whole was destroyed, yet so slowly, that no shock was produced. The circulation in the web was at first nearly natural, but in a very short time it grew gradually slower and feebler, until it ceased. The movement of the blood in the arteries first became slow, and like that in the veins; then oscillating as when the heart is removed. The capillary circulation and that in the veins gradually ceased. There was still a degree of circulation in the large vessels, and even in one or two of the capillaries, in the lung, and this organ was moved by each contraction of the heart. The heart itself still beat vigorously and regularly forty-eight times in a minute.

I again endeavoured to remove the brain and destroy the spinal marrow in a frog, so carefully as to retain the capillary circulation. The brain being removed, the capillary circulation in the web remained vigorous; a part of the spinal marrow being slowly and carefully destroyed, the circulation was evidently enfeebled; the wire being passed to the extremity of the spinal canal, the circulation in the web had entirely ceased. The beat of the heart continued, and there was some degree of capillary circulation in the lung.

I repeated this experiment upon two eels. The circulation at the extremity of the tail continued after the removal of the brain and destruction of a part of the spinal marrow; but when the whole of this latter part of the nervous system was destroyed, the circulation in the tail ceased altogether. The action of the heart continued for an hour or more.

An eel was placed so that the circulation in the tail could be observed. It proceeded rapidly. A fine wire was passed down the spinal canal. From this moment the circulation, without being at all immediately arrested, became gradually slower.

A ligature was applied tightly an inch and a half below the pectoral fin in a small eel; and the lower part was removed. The circulation still continued perfect in the pectoral fin. A stilet was then passed up, so as slowly to destroy the spinal marrow. The circulation in the fin became slower, and gradually ceased altogether.

The circulation in the tail of an eel was observed to be rapid and vigorous. A fine wire was passed slowly down the spinal canal twice. The circulation soon became enfeebled, and at length ceased in the tail, continuing vigorous in the dorsal fin. It then gradually ceased along the dorsal fin, remaining vigorous in the pectoral fin. A difference in the vigour of the circulation was frequently quite obvious within the space of an inch along the dorsal fin. The circulation at length ceased in the pectoral fin. On exposing the heart, it was still found beating regularly, though feebly.

All these experiments appear to prove that the action of the heart is enfeebled from the moment it is deprived, at once, of the influence of the brain and spinal marrow. The connexion of this organ, with the nervous system seems to be precisely of the same nature as that of the voluntary muscles. Both possess a degree of irritability independently of the large masses of the nervous system; both, if separated from these masses, gradually lose this irritability. The irritability is doubtless a faculty or property of the muscular fibre; yet it may become extinct without any obvious change in that fibre. Its continuance or renewal depends ultimately upon the masses of the nervous system.

The experiments which have been detailed, seem to prove that, from the moment of the abstraction of the brain and spinal marrow, the irritability of the heart begins to fail. The circulation is first enfeebled, then lost, in the most distant parts of the system, then in parts less and less remote. The distance to which it extends may be aptly taken as expressive of the remaining power of the heart, the principal organ of the circulation.

These experiments appear on the other hand, to disprove the opinion of Legallois,[1] repeated by M. Flourens,[2] that the power of each part depends upon that portion of the spinal marrow which is adjacent to it, and from which it receives its nerves. The spinal marrow at the extreme part of the tail of the eel, in which the circulation first disappeared, could not be destroyed from the smallness of the canal. Yet it was in this very part that the circulation was first observed to cease. To this question I shall recur presently.

4. *On the Effects of removing that part of the Medulla on which Respiration depends.*

Legallois observes at the conclusion of his Memoir, " Je n'ai parlé dans ce mémoir que de l'action de la moëlle épinière sur le cœur ; ce n'est pas que la moëlle alongée n'en exerce une aussi, mais moins considérable, et donc je m'occuperai dans une autre circonstance."[3]

M. Flourens has recently put forth a totally

[1] See page 109. [2] See pages 115 and 130. [3] Œuvres, p. 151.

different view of this subject. In a paper just published in the Memoirs of the Institute, he forms the following conclusion: "C'est surtout parcequ'elle influe, et par les points par lesquels elle influe sur la respiration, que la moëlle épinière influe sur la circulation."[1]

M. Flourens observes, "J'ai fait voir, par des expériences précédentes, qu'on peut détruire la moëlle épinière tout entière chez les poissons, sans détruire la respiration; attendu que ce n'est plus de la moëlle épinière, comme dans les autres classes, mais de la moëlle alongée elle-même, et de la moëlle alongée seule, que, chez les animaux, les nerfs du mecanisme respiratoire ou des opercules tirent leur origine.

"On peut également détruire la moëlle épinière, chez les poissons, sans détruire la circulation.

"J'ai détruit successivement, sur plusieurs carpes et plusieurs barbeaux, la moëlle épinière tout entière, sans toucher à la moëlle alongée; chez tous ces poissons, la respiration et la circulation ont long-temps survécu à cette destruction: les mouvemens du tronc et de ses appendices ont seuls

[1] Mémoires de l'Institut; Tome x.

disparu, mais la tête et la région des opercules ont continué à se mouvoir comme à l'ordinaire ; et la circulation subsistait encore, même à l'extrémité du tronc, plus d'une demi-heure après la destruction totale de la moëlle épinière."

"Enfin, j'ai détruit, sur plusieurs grenouilles, toute la moëlle épinière, hors le seul point de la moëlle cervicale duquel naissent les nerfs de la gorge (c'est-à-dire de la partie mobile de l'appareil respiratoire de ces animaux), et la circulation, comme la respiration a survécu pendant longtemps."[1]

I have quoted these experiments at length, because they not only bear upon the present question, but still more distinctly upon the question to be next considered.

In regard to the present question, indeed, there is an experiment of a far more decisive kind. Having seen that in some species every part of the spinal marrow might be removed, except that on which respiration depends, it should have been a question whether this very part might not be removed, reserving the other parts.

I have performed this experiment, and the fol-

[1] Mémoires de l'Institut; Tome x.

lowing is the result:—At nine o'clock in the evening, the medulla oblongata of a frog was removed. A considerable portion of blood was lost. Respiration ceased entirely and permanently. The circulation became languid. It gradually recovered, however; and at midnight, it was perfectly restored. Every precaution was taken to keep the surface constantly moist and cool. At nine o'clock on the following morning, the circulation was perfect. The respiration was annihilated. At the expiration of thirty-six hours the circulation was still perfectly vigorous,—perfectly unchanged.

I repeated the experiment:—At half after eight o'clock, the spinous process of the third vertebra in a frog was removed, and a fine wire was passed to the end of the brain; the eyes were retracted and respiration ceased. The wire was passed a second and a third time, inclined to each side, until the brain and medulla oblongata were entirely destroyed. Respiration had ceased; the circulation in the web continued perfect, and at eleven o'clock was still apparently unimpaired. At nine o'clock, on the succeeding morning, the circulation was still distinct, but feeble. At eight o'clock in the evening, twenty-four hours after the destruction of the brain and medulla oblongata, there was still a slight circulation in the web; the capillary circulation in the lung was good, and the beat of the heart vigorous.

The experiment was then made upon an eel. The medulla oblongata and brain were destroyed. An hour afterwards all respiratory movements were found to have ceased, but the circulation in the tail, and the beat of the caudal ventricle remained good. This was still the case at eleven o'clock. The next morning the circulation had ceased.

It is quite obvious, from these experiments that the circulation no more depends upon the medulla oblongata than upon the medulla spinalis. I had previously determined that it does not depend upon the mere acts of respiration; for in the toad, in which respiration was entirely arrested, and from the lung of which Plate VIII. was taken, the pulmonary circulation continued unimpaired during more than four hours.

The conclusion to which we are led, then, is still that of Legallois, in opposition to that of M. Flourens: "En un mot, soit par ce procédé, soit par celui des ligatures, il n'y a aucune portion de moëlle épinière qu'on ne puisse empécher de coopérer à entretenir la circulation sans que cette fonction soit arrêtée ; il n'y en a aucune qui ne puisse devenir suffisante pour l'entretenir ; et l'on trouve qu'à tous les âges une portion quelconque fournit au çœur des forces capables d'entretenir la circulation dans toutes les parties qui reçoivent leurs nerfs de cette portion."[1] Only we cannot assent to the concluding part of the paragraph. "Mais, de quelque manière qu'on s'y prenne, toutes les fois que l'on va jusqu'à anéantir l'action de la moëlle dans toute son étendue, la circulation est arrêtée sans retour."[2]

5. *On the Effects upon any given part, of removing that portion of the Spinal Marrow, from which it derives its Nerves.*

Upon this question Legallois[3] and M. Flourens[4] were agreed.

But this first view of the subject seems to be at variance with M. Flourens's more recent opinion, and with his experiments just quoted. The spinal marrow in frogs, and in some kinds of fish was destroyed, yet the circulation in the lower

[1] Œuvres, pp. 369—370. [2] See p. 136. [3] Ibid.
[4] Du Système Nerveux, p. 196.

parts of these animals, the very parts supplied by this portion of the spinal marrow continued.

M. Flourens omits to inform us by what means he judged of the continuance of the circulation. The following experiment, whilst it confirms that of M. Flourens in its results, supplies this deficiency.

At a quarter to four o'clock, the lower portion of the spinal marrow in a frog, from the third vertebra inclusive, was destroyed by a fine wire. The breathing continued. At a quarter to six, the circulation in the web still continued good. The wire was now passed upwards, so as to destroy the medulla oblongata and brain. The respiration ceased immediately. The circulation very gradually declined, the arteries became pulsatory, then much larger, and like the veins, except for the direction of the globules. The capillaries next began to become less numerous, some disappearing. The breadth of the arteries became quite extraordinary. The nerves and arteries became much alike, and equally pale and slow. As the immediate effect of the shock, the arteries became small, and one became impervious, for a short time, to the blood. It gradually recovered.

At ten minutes after seven o'clock, a very fine wire was passed from the part of the medulla covered by the spinous process of the third vertebra, to the bottom of the spinal canal and withdrawn towards one side. The respiration and the circulation in the web were unaltered. The wire was then introduced again and moved about in every direction until there was no longer any spasmodic motion of the limbs. The respiration and circulation still continued perfect. At eleven o'clock these functions still continued good. At eight o'clock in the following morning, and at the same hour in the evening, twenty-four hours after the destruction of the spinal marrow, the respiration and circulation still continued good.

This experiment does not succeed equally well with the eel. At half-after nine o'clock, a fine wire was passed into the spinal canal of an eel, just below the medulla oblongata, and downwards so as to destroy the spinal marrow. The circulation in the tail was immediately enfeebled; the beat of the caudal ventricle ceased, the respiratory acts continued. At eleven o'clock all circulation in the tail had disappeared, but that of the pectoral fin, and the acts of respiration continued. The next morning all vital phenomena had ceased.

6. *Of the Effect of destroying the entire Brain and Spinal Marrow, by successive portions, at distant intervals.*

We are led by all these experiments to consider the results so well and so fully expressed by Legallois in the following passage of his work:

"C'est encore d'après les mêmes principes qu'en détruisant la moëlle successivement par petites parties, et en mettant un certain intervalle entre chaque destruction, on en peut détruire, sans arrêter la circulation, une longueur beaucoup plus grande que celle qui aurait suffi pour produire cet effet si elle eût été détruite en une seule fois: car la destruction d'une petite étendue de moëlle, insuffisante pour arrêter la circulation générale, la diminue toujours beaucoup dans les parties qui tirent leurs nerfs de la moëlle détruite, et y fait, jusqu'à un certain point, l'office d'un ligature. De plus, les forces du cœur étant affaiblies par cette operation, la circulation générale se concentre et ne conserve un peu d'activité que dans les parties voisines du cœur; ce qui produit encore un effet analogue."[1]

In fact, if a portion of the nervous masses be removed, and if this be compatible with life, the animal is reduced to a lower degree in the scale of organized beings. It lives as a still lower animal. And it becomes capable, on this principle, of enduring new privations. I doubt not that, in this manner, the whole brain and spinal marrow may be removed, and that the animal may live, sustained by the mere ganglionic masses, and the cutaneous respiration.

The principle just enounced, is entirely different from that of Legallois, that of Dr. Philip, or that of M. Flourens. The first thinks that the extent of the circulation is diminished, and that an enfeebled heart may carry on a minor circulation. The second ascribes the difference to the mode of removing the nervous masses. M. Flourens supposes the medulla oblongata to be essential to the circulation, as it is to the respiration. But I suppose that the entire circulation continues. I suppose also that crushing is equally avoided in the two experiments of re-

[1] Œuvres, p. 369.

moving the whole nervous masses at once, or small portions of them at distant intervals. And I suppose that the medulla oblongata is removed with the brain and spinal marrow.

It was after having watched the experiment given, pp. 130, 131, and finished its details, that these views occurred to me. It was nine o'clock, A. M. Thirty-six hours had elapsed from the time at which the medulla oblongata was destroyed. I removed the entire brain and spinal marrow. At one o'clock, four hours after the whole of the brain and medulla was removed, the circulation was still obvious enough in the arteries, capillaries, and veins, and likely to continue, although paler and more languid. At four o'clock, there was still an obvious movement of globules along the arteries and veins. And even at nine o'clock there was still a very slight degree of circulation in the minute arteries and veins.

To this experiment the following one may be added:

Similar phenomena were observed in the subsequent progress of the experiment detailed in p. 135. At eight o'clock in the evening, rather more than twenty-four hours after the destruction of the spinal marrow, the respiration, and the capillary circulation continued good; the fine wire was now passed upwards so as to destroy the medulla oblongata and brain. Respiration ceased. The circulation in the web was immediately enfeebled; an artery distinctly seen, became much enlarged, but not distended. In ten minutes the circulation was feebler still; the rapidity became nearly the same in the arteries and veins. On the succeeding morning and evening, the circulation still continued. It was still obvious and indeed apparently little altered on the third day, after noon, forty hours after the entire destruction of the brain and medulla. In the evening all circulation had ceased; and on exposing the heart there was no pulsation.

The first part of these several experiments reduced the animal many degrees in the scale. In the first experiment it subsisted without medulla oblongata or pulmonary respiration. Its nervous system was reduced; its respiration was merely cutaneous. In this state, it was enabled to endure the further and entire privation of its brain and spinal marrow without the immediate cessation of the power of circulation. In the second experiment the extent of the nervous system was lessened. The animal descended lower in the scale of beings and became capable of bearing further mutilations.

The extent of the circulation was not lessened, according to the idea of Legallois; for it was watched all along in the web. There was neither more nor less of crushing than in experiments in which the capillary circulation in the web speedily failed. The medulla oblongata was removed, without producing the effects observed by M. Flourens.

It is plain that some new principle must be discovered, to explain a fact so extraordinary, so well attested by Legallois' experiments and my own. I have proposed a principle which appears most probable to me, and which accords with what we see in an earlier stage and in a lower order of animal existence.

Even in these experiments, the most remarkable of all that have been performed relative to this subject, from the moment the whole of the brain and medullæ was destroyed, the circulation gradually, progressively, but slowly failed. It cannot, therefore, by any means, be said that the circulation is independent of the brain and spinal marrow.

II. Of the Experiment of Stimulating the Brain and Spinal Marrow.

I have been greatly disappointed in repeating the experiment of applying stimulants to the brain and spinal marrow, in the batrachia.

Dr. Philip's account of this experiment is given in the following terms:—

"Dr. Hastings had found, tha immersing the hind legs of a frog in tincture opium, in less than a minute deprives it of sensibility. This does not arise from any action of the opium; a watery solution of opium, we found, however strong, does not produce the effect. It is produced by simple spirit of wine. It is remarkable, that if simple spirit of wine is used, the animal expresses pain; if tincture of opium, little or none. The author has just mentioned the reason why it is necessary, in order to judge of the result of this experiment, that the animal should be rendered insensible. A frog, being thus deprived of sensibility, the brain and spinal marrow were laid bare, and the chest opened. The heart was found contracting with vigour. Spirit of wine was applied to the spinal marrow with an immediate and evident increase of the action of the heart. It was then applied to the brain with the same effect. Watery solutions of opium and tobacco were also applied to both, with precisely the same effect as in the rabbit. The increase of action from the opium and tobacco was much less than from the spirit of wine, and was soon followed by a great diminution of action. The increase of action was least, and the diminution greatest, from tobacco. On washing off the opium and tobacco with a wet sponge, the heart immediately beat more strongly. The different parts of this experiment were frequently repeated with the same result. It is remarkable that the motion of the heart could be affected by stimulants applied to the brain and spinal marrow, after they had all ceased to produce any effect on the muscles of voluntary motion through the medium of the nervous system, and long after the circulation had ceased."[1]

"Part of the cranium of a frog was removed, the web of one of the hind legs brought before the

[1] On the Vital Functions; Ed. 3. pp. 69—71.

microscope, and the circulation in it observed. The animal was then rendered insensible by the immersion of the other hind leg in laudanum. The insensibility did not in the least affect the circulation in the web before the microscope. Spirit of wine was then applied to the brain, with an evident increase of the velocity of the blood in the web. The same effect was produced in a less degree by watery solutions of opium and tobacco. After the tobacco had been applied for about half a minute, the motion of the blood was much less rapid than before its application. On washing off the tobacco, the velocity of the blood increased, and was again lessened on applying it. This was repeated several times with the same effects."[1]

1. *Of the Effects of Alcohol and of Opium upon the Batrachia.*

In the first place, on applying laudanum or spirit to the cutaneous surface of a frog, so as to induce insensibility, I was surprised to find the circulation in the web greatly enfeebled; and on applying a watery diffusion of opium, in the proportion in

[1] On the Vital Functions; Ed. 3, p. 80.

which it exists in laudanum, I was equally surprised to find the simultaneous occurrence of an obliterated circulation and of a complete tetanus.

In the second place, on applying alcohol to the surface of the brain and spinal marrow, after inducing insensibility by laudanum, I could discover no acceleration whatever, either in the beat of the heart or in the circulation of the blood in the web. I shall briefly detail my experiments.

I applied laudanum over the back part of a frog carefully avoiding its contact with the web. In less than half an hour the respiration and all sensibility had ceased, and the capillary circulation became, at the same time, more distinctly pulsatory in the arteries, and more and more slow and feeble in the capillary vessels and veins. This effect became gradually more marked, and in two hours the circulation had ceased almost entirely in all the three sets of vessels. I now washed off the laudanum and placed the frog in water. The circulation at first gradually, afterwards more speedily, returned, and became very vivid and vigorous, even before there was the slightest return of the respiration; the respiration and sensibility at length also returned completely. The laudanum was reapplied and again removed with precisely the same effects. The insensibility was so perfect that the eyes were not retracted on being touched. The recovery was prompt and complete.

I repeated the experiment with diluted alcohol, with similar effects.

The experiment was now made with a mixture of opium and water. It was long before it produced any effect. At length, however, the circulation in the web ceased, and the animal became affected with complete tetanus.

The same effect was produced more speedily on inducing the animal to swallow a few drops of the opiate solution.

These effects of laudanum are precisely what were observed by Dr. Alston of Edinburgh more than a century ago. Dr. Alston relates his experiments in the following characteristic manner:

"In the physick garden at *Holyroodhouse* (where all the Experiments on Frogs were made) I one evening put a big strong Paddock into a Pot of Water, wherein a small Quantity of *Opium* was dissolved; it soon appear'd to be uneasy, by making strong Efforts to get out of it, but in a short time it flag'd or grew dull, making very little

Motion, and next Morning it was dead and much swelled.

"In Presence of, and assisted by Mr. *Robert Fullarton*, a curious Gentleman, and very dextrous in Microscopical Observations (in August 1733) I conveyed through a Small Glass Tube a few Drops of a Solution of *Opium* in Water into a Frog's Stomach, and putting the Animal into a Glass Cylinder, adapted it so to a good Microscope, that we had a distinct view of a part of the Membrane betwixt the Toes of its hinder Foot, where the Circulation of the Blood may easily be seen. My Design was, since I found *Opium* killed frogs, to observe if there was any visible Change made by it in the Blood itself, or in its Motion; neither of us could indeed see any Alteration of the Blood as to its Consistence, Colour of the Serum, Magnitude, Figure or Colour of the red Globules; but we very distinctly saw a surprising Diminution of the Blood's Velocity, for it did not move half so swiftly as it use to do in these Creatures. We alternately looked at it again and again, and in less than half an Hour saw the Velocity of the Blood gradually increase, the uneasy Frog recovered its wonted Vigour, and the Blood its common celerity; upon which we took out the Paddock, put it in a bason of clean water, and allowed it half an hour to refresh itself, then gave it another Dose of *Opium*, fixed it to the Microscope with all expedition, and viewed it as before; the blood then moved yet slower than it did the first time; and, its Velocity gradually decreasing, at length it stagnated, first in the smaller, then in the larger vessels, and in about a quarter of an Hour the Animal expired. One thing was very observable all along, viz. That notwithstanding the diminished Velocity of the Blood, there was no sensible Diminution of the Frequency of the Pulse; yea, when there was no Circulation or progressive Motion of the Blood in this part, the Pulse was visible by an undulating Motion; that is, the Blood returned as far back at every *Diastole* of the Heart, as it was protruded by the preceding *Systole*; this continued till the Frog was quite dead, or at least appeared to be so. When we had lost all Hope of its Recovery, I open'd it, and found nothing in its Stomach but a clear Mucus like a Gelly, a little coloured with the *Opium*, of which it was full; every thing else seemed perfectly natural. This Experiment we frequently repeated, and it had always the same Appearances and Event. The Recovery, however, of one of the Frogs, which for a considerable Time seemed to be dead, is not to be omitted. My Friend and I one Evening killed, as above, a Couple of Frogs, with *Opium*. One of them, which was the strongest, I laid half in Water on a Tile, in the Bottom of a Water-Pot, that if it recovered it might sit either wet or dry as it liked best; the other I left on the Earth dry under a Hedge. Next Morning when I returned to the Garden, I found the one under the Hedge dead as I left it, but the other in the Water-Pot was alive, and appeared to be in perfect health.

" While we were thus employed, another thing occurred, which though foreign to the present subject, it may not be amiss to mention. One of the Frogs we got for the above Experiments, had not the use of one of its hinder legs, which was of a pale reddish Colour. This made me desirous to observe by the Microscope the Circumstances of the Circulation in this paralytick and apparently inflamed member; and we found that the red Globules were entirely dissolved;

that the Blood-vessels were distended with a reddish homogeneous Liquid, as if the Part had been injected with a bloody Water; and that neither Sense or Motion remained in it."[1]

It is singular that this author did not discover that the paralysis, of which he speaks, was, in fact, tetanus; and that Drs. Philip and Hastings have overlooked this peculiar effect of opium altogether. It is precisely similar to that of strichnine. And it is equally produced, whether the opium be applied externally or given internally. With the accession of this tetanic affection, there is a total annihilation of the respiration and capillary circulation. It is remarkable, that an aqueous solution of opium should produce this effect, whilst the influence of this drug, in laudanum, should be entirely superseded by that of the spirit.

2. *Of the Effect of the Application of Alcohol to the Brain or Spinal Marrow.*

But I proceed to the detail of the experiments of applying alcohol to the brain and spinal marrow.

[1] Edinburgh *Medical* Essays, Ed. 3. Vol. v. pp. 128—130.

Having entirely destroyed the sensibility in a frog by the application of laudanum to the surface of the animal, the brain and spinal marrow were laid bare, and alcohol was applied successively, first to the former, and then to the latter. But the beat of the heart was precisely the same in number, and apparently the same in force before and after these applications of the spirit.

This experiment was repeated with the utmost care, and before several competent witnesses, with precisely the same result. The heart continued to beat forty-two times in a minute for a considerable time after the application of the alcohol to the brain and spinal marrow, and with the same apparent force.

Having applied laudanum to the skin of a frog, the circulation in the web became slow, as usual; the respiration nearly ceased. The brain was now laid bare, and alcohol was applied. One particular arterial trunk in the web, with its branches, and the adjacent capillaries, were carefully noted. Not the slightest acceleration of the circulation of the web was detectible. Indeed the circulation became slower rather than quicker, and ultimately decidedly slower. The spinal marrow was now laid bare, and alcohol applied along its whole course. An artery and vein crossing each other were carefully watched. Had there been the slightest effect upon the circulation, it must have been observed. But there was none. In both instances the web had been moistened just before the application of the alcohol; and it was otherwise untouched. Nothing could interfere with a change in the flow of blood, had there been any cause tending to produce such an effect. On exposing the heart, it was found to beat slowly. The circulation was seen in the larger pulmonary arteries. It had ceased in the capillaries.

I believe there may be one difference between Dr. Philip's experiments and my own. I might apply the laudanum more effectually; yet I only induced insensibility, the effect desired. The moment this effect was obtained, I proceeded with my experiment.

I have not thought it necessary to repeat the experiment, because it must, at best, be a complicated one, and therefore unsatisfactory. It also appeared to me to be an improbable one. It were singular, indeed, if spirit applied to the surface should enfeeble the circulation, and, if applied to the brain and spinal marrow, should quicken it.

III. Of the Experiment of Crushing the Brain and Spinal Marrow.

There can be little doubt that Dr. Philip's explanation of the discrepancies in Legallois' experiments, and of the difference between removing and crushing the brain and spinal marrow, is partly correct. But, having observed certain effects upon the action of the heart from crushing the brain or spinal marrow, Dr. Philip deduces from them certain conclusions in regard to the peculiar functions of these parts of the nervous system. It may I think be doubted whether these conclusions be legitimate. For it may be asked,—Were the results observed, the effects of crushing these organs specially, or the mere effect of violence and injury inflicted generally? What would be the comparative results of crushing other parts or organs, as the stomach, a limb, &c.? And lastly, does the experiment of crushing the brain and spinal marrow really lead to any accurate knowledge of the peculiar functions of these individual organs?

And the influence of crushing, compared with simply removing the nervous masses, is, I think to be taken in conjunction with the influence of time allowed to elapse between successive parts of the operation on which I have already said so much, before we can fully explain all the important facts mentioned by Legallois.

Dr. Philip observes, that in Legallois' experiments "the spinal marrow was always crushed, by a stilet of the same dimensions with the cavity of the spine;" whereas, in his own it was "either removed, or destroyed by a comparatively small wire, moved about in it till its functions ceased."[1] I have not been able to find this circumstance mentioned, in Legallois' work. On the other hand, he speaks,[2] of introducing the stilet between the vertebræ into the spine; so that I think the instrument could not be of so large dimensions as Dr. Philip imagines. And other circumstances prove that the effect observed did not entirely depend upon the mode of operation. A paragraph at page 106 of Legallois' work illustrates this point, whilst it details an interesting and valuable fact, which

[1] P. 88.
[2] Œuvres de Legallois, Paris, 1824, p. 100.

has a strict reference to the other part of our present subject.

"En général, vers l'âge de dix jours, les effets de la destruction de la moëlle épinière offrent beaucoup de variétés. Il n'y a de bien constant, à cet âge, que la cessation subite de la circulation par la destruction simultanée des trois portions de cette moëlle, et son affaiblissement plus ou moins grand par celle d'une quelconque de ces portions. Cela paraît dépendre de ce que l'influence de chaque portion sur la circulation, augmentant avec l'âge, c'est vers l'âge de dix jours qu'elle approche de son *maximum*. En effet, la même portion de moëlle qui, étant détruite à cet âge, n'arrête pas encore la circulation, l'arrêtera constamment quelques jours plus tard."

There still remains the experiment of irritating the brain and spinal marrow mechanically, in the batrachia. On this subject, I beg, for the present, to refer to the experiments of Spallanzani, Fontana,[1] Dr. Philip and, in regard to fishes, of Mr. Clift.

[1] See pp. 88—93.

CHAPTER IV.

OF THE INFLUENCE OF OTHER ORGANS UPON THE HEART AND CIRCULATION.

Whatever may be the character of that connection which subsists between the brain and spinal marrow and the heart and the circulation, the same thing is observed, in regard to other organs or parts, and the organs of circulation. There may be a difference in degree; but there is none in kind. The heart may be more independent of a limb than of the spinal marrow; it may be less influenced by crushing the former than the latter. But still the principle is the same. It is one of mutual connection, rather than of individual function. To crush the brain, no more teaches us the functions of the brain, than to crush the stomach or the hand, teaches us the functions of the stomach or the hand. Such experiments alike set forth the wonderful συμπάθεια of the various organs.

1. *Of the Effects of Injuries and Violence inflicted upon a Viscus, a Limb, &c.*

It is perfectly obvious that, if to crush some other organ, or a limb, produce the same effect upon the heart which arises from crushing the brain and spinal marrow, no deduction can be drawn from either experiment, in regard to the function peculiar to any one of these parts or organs. It is the act of crushing, the act of violence or shock, generally, the effect of which is seen. And if, in one instance, we were to conclude that the heart and the vessels of the circulation were independent of the brain and spinal marrow, yet impressible through them, we must also infer the same thing in regard to the stomach, or to a limb, and the organs of circulation. A limb may be amputated, and the animal still survive with unimpaired powers of life. Yet the power of the heart may be so impressed by the violent crushing of a limb, that it shall cease to beat altogether. If any of the viscera be violently crushed, the immediate fatal issue is almost certain.

A robust and healthy waggoner fell down, and the wheel of his heavy waggon passed over the abdomen. The beat of the heart was so enfeebled, that the pulse could scarcely be felt. No reaction took place. The effect was perfectly similar to that of crushing a portion of the brain and spinal marrow. On examination, the ileum was found lacerated in two places.

A man had his arm drawn in, and violently crushed and torn off, by some machinery. The action of the heart failed and never rallied.

Every one will remember the melancholy accident which occurred to the late Mr. Huskisson. The tremendous vehicle passed over the thigh. The action of the heart failed, and the surgeon waited for reaction,—for an opportunity for amputation,—in vain!

These facts are familiar to all. They prove that there is nothing peculiar to the individual organ crushed, in its effects upon the heart, the circulation, and the general system; and therefore that no physiological deduction, in regard to the nature and office of any particular organ, can be drawn from an experiment of this kind. The only point really established is that well-known, yet wondrous, connection in the animal frame, of every part or organ, with every other part or organ.

The whole system may be compared, in this point of view, with rings entwined together. They mutually support each other. Any one may be removed, without destroying the form of the rest. But their strength is immediately impaired. And if one be violently crushed, the others will scarcely escape from distortion. These rings may represent the nervous, vascular, and organic circles in the animal frame.

I confess then that I think no physiological deduction can be drawn from the experiment of crushing the brain and spinal marrow, in regard to the functions of these organs.

That precisely similar effects do result from crushing the stomach or a limb, in animals perfectly insensible to the infliction of pain, is proved by the following experiments.

A frog was made perfectly insensible by the application of laudanum or alcohol. Its respiration ceased. It did not move, on the application of any irritant. The circulation in the web was carefully observed. When it had long continued in the same enfeebled state without change, the thigh was crushed. The circulation in the minute and capillary vessels ceased at once, and never returned. The stomach was now crushed in the same manner. The heart ceased to beat for many seconds. Its beat then returned,—but never regained its former force. The effect was precisely such as was observed by Legallois, on crushing the spinal marrow.[1] There was not the slightest indication of pain in either experiment.

The experiment was repeated. The result was so perfectly similar, that a note was written, at the time, stating that the experiment need not be again repeated.

Nevertheless it was repeated several weeks afterwards with precisely the same results. The action of the spirit upon the cutaneous surface had arrested the respiration, destroyed all sensation, and induced considerable languor in the circulation in the web. When this state had continued uniform during a considerable time, the other limb was crushed by a hammer. There was not the slightest motion of the animal or expression of pain, so deep was the insensibility. The circulation in the whole web ceased instantly.

[1] See pp. 110, 111.

The spinal marrow being removed in an eel, the circulation became, at length, much enfeebled in the pectoral fin. The part one inch and half below the heart was crushed. The circulation in the pectoral fin now ceased suddenly and entirely.

In an eel, in which the brain had been carefully removed, and the spinal marrow destroyed, the stomach was violently crushed with a hammer. The heart which previously beat vigorously sixty times in a minute, stopped suddenly and remained motionless for many seconds. It then contracted; —after a long interval it contracted again, and slowly and gradually recovered an action of considerable frequency and vigor. No experiment can more clearly demonstrate the effect of violence inflicted upon the system generally. The experiment is the more remarkable because the connection and influence of the brain and spinal marrow were entirely removed. The organic structures must have been the medium through which the effect of the violence was conveyed to the heart.

If the heart and circulation be viewed as independent of the brain and spinal marrow, yet impressible through them, this is equally true of their relation to the stomach or a limb. But in fact it is impossible to remove the brain and spinal marrow at once without immediately impressing the powers of the circulation, so that the motion of the blood in the capillary vessels immediately fails in the extreme parts of the system, and gradually, in those placed nearer the heart. The powers of the circulation are, on the other hand, totally independent of any of the limbs. Yet they may be suddenly destroyed through them.

Were we to draw any inference from these facts, relative to the functions of these various parts, it must be that all have the same function,—which would be preposterous.

The physiological deduction which does flow from them is that so much insisted upon by Hippocrates himself, that every organ or part influences, and is influenced by, every other;—that there is a prevailing sympathy.

2. *Of the Influence of Inflammation and other Diseases of various Organs, upon the Heart.*

Similar deductions flow from observing the effect of inflammation or other diseases of a part or organ, upon the action of the heart. The effect is one which differs in degree rather than in kind.

Inflammation of the brain, the pleura, the stomach, or a limb, produces its effect upon the heart and circulation.

The difference of this influence in arachnitis and pleuritis is imperceptible; so is that of inflammation of the substance of the brain, and of the lung.

The effect of inflammation of the stomach and bowels, indeed, is peculiar: the pulse is small; the capillary circulation is impaired.

On the other hand, gangrene of any organ, or of a limb, impresses the heart in such a manner, that its function is first singularly impaired and then annihilated.

Every thing proves that the influence of injury is similar, whether it be inflicted upon one organ or another, or even upon a limb. The same deduction of a general sympathy, and the same absence of any physiological deduction as to the functions of individual parts or organs, obtains.

CHAPTER V.

OF THE EFFECTS OF THE APPLICATION OF IRRITANTS TO THE WEB OF THE FROG.

I HAVE always distrusted the experiments in which irritating or stimulating substances have been applied to the web of the frog, in order to determine the question of the irritability of the capillary vessels. This kind of experiment involves too many causes of complication, to admit of any conclusion being drawn from them, respecting either the nature or function of the minute and capillary vessels in health, or their modifications in disease.

The first effect of applying an irritating substance to the web of a frog, is the infliction of fear and pain. Fear singularly arrests the flow of blood. Pain alone would probably immediately accelerate the circulation.

But, in fact, the pain inflicted immediately leads to another effect,—that of struggling. This, like every muscular contraction, induces various effects upon the circulation in the minute and capillary vessels. The course of the blood becomes arrested, or oscillatory, and variously irregular.

The next effect produced by this experiment, is, according to the nature of the substance applied, a various degree of constriction or corrugation of the external membranes of the web itself. This, as we have seen in Chapter II, § 6, will induce various impeded or even retrograde movements in the globules of blood.

In the next place, there can be no doubt that the application of a stimulant to the web, will variously affect the textures of the subjacent minute and capillary vessels, and induce proportionate changes in the motion of the globules of blood.

Lastly, there can be no doubt, I think, that the influence of the application of some substances, extends even to the contents of the minute and capillary vessels.

How shall we, in the midst of a question so complicated, disentangle and isolate any effect of a purely vital kind, upon the muscular and contractile texture of the vessels? How shall we ascertain whether this individual texture be excited or debilitated? And if it be impossible to determine the immediate effects of stimuli, how shall we distinguish such as are secondary and constitute morbid processes, viewed as mere affections of the vital properties?

Still the experiment of applying stimuli to the web, is one full of interest, if we confine ourselves to the mere observation of facts. On a view of such an experiment, we are led to consider other actions and relations besides those that are vital. Indeed, I think it very obvious that some of the effects of irritants applied to the web of the frog, as well as other living animal membranes and textures, are of a *physical* character; others may be of a *chemical* nature. The operation of most of the causes of inflamation are of the former order. Mechanical injuries; heat and cold; alcohol, ammonia, the muriate of soda, &c. appear to possess an agency of this kind. Under their influence the blood frequently becomes stagnant, frequently extravasated. The operation of inflammation is apparently one not so much excited by these agents, as set up by nature to remedy their deleterious effects. Stagnation and extravasation are sufficient to explain the tension and pain in the part subject to the action of causes of inflammation.

The immediate effect of the causes of inflammation is plainly physical, as well as vital, if it be vital at all. Inflammation itself is that process which is set up to remove the effects of irritation, and does not consist in the mere enlarged or debilitated condition of certain vessels, or the impeded motion of the blood contained in them.

To be satisfied of the first of these propositions we have but to read the detail of experiments given by Dr. Hastings,[1] or to repeat and observe the experiments themselves.

I have never been able to detect any phenomenon from the effect of irritants applied to the web of the frog, which would lead to the idea of increased or diminished action of the minute or capillary vessels.

The early effect of alcohol is stagnation of the

[1] See the Treatise on Inflammation of the Mucous Membrane of the Lungs; pp. 51, et seq.

blood. This stagnation may be confined to either the upper or lower layer of vessels, as depicted in Plate III, if proper precautions be taken in applying the stimulus to the upper or under surface. I have also repeatedly witnessed a singular phenomenon. In a large vein, the globules have partly adhered to its internal surface, whilst in its central part, they have flowed on with more or less regularity. I have also seen a considerable stagnation cease all at once, and yield to a free flow of the globules of blood.

These facts naturally lead to the conclusion, that the internal surface of these vessels, is particularly affected.

The application of a solution of the muriate of soda is more prompt, and still more remarkable in its effects, than that of alcohol. Stagnation, and a deepened colour of the blood, are simultaneously produced. This fact would lead us to imagine that the stimulus penetrated even into the internal vascular canals.

Is there exosmosis or endosmosis? The first, might induce stagnation; the second might induce the change of colour, of the globules of blood.

The subsequent changes are very remarkable.

But I must reserve the further discussion of the effects of stimuli, of the phenomena of inflammations, and its terminations, to a future opportunity. I have attained my present object, which was merely to shew that the effects of irritants or stimuli applied over the minute and capillary vessels, are not to be resolved into mere increased or diminished action. I believe their first effect is either physical or chemical. The subsequent links in the chain are doubtless vital; but still, such as are not to be resolved into mere increased or diminished action. In fact they must rank amongst the most intricate and obscure of the animal economy. M. Kaltenbrunner has very wisely and philosophically confined himself to the detail of the obvious phenomena of inflammation, in a work which cannot, in my opinion, be estimated too highly.[1]

The constriction of a single vessel at one particular point; the apparent adhesion of the globules of blood to the sides of the vessels; the change of colour and the change of form of the globules, are facts which clearly shew that the whole parietes of the vessels, their internal lining, and their

[1] Experimenta circa Statum Sanguinis et Vasorum in Inflammatione; auctore Georgio Kaltenbrunnero. 1826.

contents, are alike subject to change by the application of various stimuli. The first effect appears to be distinctly of a physical or chemical character; the second is produced in cases in which the circulation is previously languid, by gentle pressure with mere blotting paper; the third is, in some instances, probably the result of the actual imbibition of the substance applied.

It is a singular circumstance that phenomena may be produced by mere gentle scratches by a needle, which cannot be distinguished from the effect of alcohol. It is difficult to imagine that one of these acts upon the irritability of the vessels, when the action of the other is so entirely physical.

Here then I conclude my observations upon this subject. For I reserve the investigation of the series of phenomena which occur in inflammation, and in restoration on one hand, and gangrene on the other, to a future opportunity.

CHAPTER VI.

A BRIEF ACCOUNT OF THE SINGULAR PHENOMENON OF A CAUDAL HEART IN THE EEL.

It is well known to the comparative anatomist, that the fish tribe possess only a simple pulmonic heart. This organ gives origin to a large artery, which, soon after it quits the heart, divides into four branches, of which one pair goes to each pair of branchiæ. From the branchiæ, the blood is returned through vessels which unite and forms the aorta. The aorta, in its turn, again subdivides and sends branches to the different parts of the body. From each of these the vessels again reunite, form the vena cava, and convey the blood once more to the heart.

Through the whole of this course, it has been supposed that the pulmonic heart alone, with the aid of some subsidiary powers of the circulation, propelled the blood.

I have discovered a structure in one species of fish, which will lead us to view this opinion with distrust, and which will point out to us the fact of an unsuspected addition to the power and action of the heart, in some species of animals.

This structure is seen, even with the naked eye, in the tail of the eel. Its form, action, and connexions are, from the degree of transparency of the part, still better traced by the assistance of the microscope. Placed under this instrument, a particular spot near the extremity of the tail in the eel, easily discovered, has the appearance represented in Plate X.

The drawing represents the ventricle of this caudal heart. The different vessels unite and form a connexion with this ventricle near its highest point.

The course pursued by the blood in these vessels is marked by the arrows, and uniformly tends towards the highest point of the ventricle; from this point it seems to be slowly propelled or drawn into the ventricle; by a sudden contraction of this, it is gathered into a drop, and propelled with great velocity, and at first with the peculiar appearance of successive drops, along a vessel which ascends along the inferior spinal canal, and which must, although it pursues a direction towards the heart, be considered an artery. The blood is so divided in the ventricle itself, as to appear pale. At each contraction of the ventricle, it is collected into a drop of a vivid or deep red colour.

The action of this caudal heart is entirely independent of the pulmonic heart; whilst the latter beats sixty, the former beats one hundred and sixty times in a minute. It continues for a very long time after the influence of the pulmonic heart is entirely removed.

As the pulsations of the caudal heart become languid, distinct oscillations of the blood are seen in the adjacent vessels, even to some distance from the organ itself.

The vessels which issue from the caudal heart appear to have a particular distribution to the spinal marrow. A stilet passed down the spinal canal, induced, in several instances, a distension of the vessels leading to the caudal heart, and frequently a slight extravasation of blood.

The capillary circulation and the pulsation in the heart of the tail continued a few minutes after the division of the animal, one inch and a half below the pectoral fin; but the former soon became oscillatory, and then ceased, whilst the pulsation in the heart still continued.

Whether this structure be single, or multiplied, whether it be peculiar to the eel, or common to other fish, as animals having a pulmonic heart only, or to other species characterized by the length of their bodies, are questions which I purpose to examine hereafter.

In the mean time I have ventured to designate this singular organ by the term of the CAUDAL HEART.

CHAPTER VII.

OF THE EFFECTS OF WARM WATER UPON THE MUSCULAR TEXTURES.

I have alluded, in a former part of this Essay, to an interesting experiment of M. Edwards. In one of the most splendid and connected series of observations in physiology [1] since the days of Spallanzani, M. Edwards has treated of the influence of water varying from 10° to 42° of the centigrade thermometer, or from 50° to 108° of Fahrenheit, upon the species of the order batrachia plunged into it. The life of these animals continues longer as the temperature falls, and terminates sooner as the temperature rises, within these limits. At the highest point, or 108° Fahrenheit, life in the batrachia is extinguished, accor-

[1] De l' Influence des Agens Physiques sur la Vie : par W. F. Edwards, D. M. A Paris, 1824.

ding to this accurate experimenter and observer, almost instantaneously. There is one thing in M. Edwards' account which might lead to error. It is, the inference which would naturally be drawn from it, that the kind of death in question is asphyxia. It is plain on the contrary, that water of the temperature of 108° Fahrenheit, has an influence upon the batrachia more immediately destructive of life than the mere suppression of the functions of the lungs or of the general surface. The promptitude with which it acts, is a sufficient proof of the truth of this statement. The mode of its operation is equally decisive of the same fact. M. Edwards observes—" à mesure que l'on élève la température, on voit un petit nombre de degrés d' une chaleur tempérée, produire des decroissemens considérables dans l'existence de ces animaux. On voit aussi leur agilité augmenter, jusqu'à ce qu'enfin elle devienne tres-grande au degré où la température leur est si promptement fatale."[1]

Observing in one instance that water of the temperature of 108° Fahrenheit did not produce immediate or complete annihilation of sensibility,

[1] P. 28.

I resolved to employ a temperature of 120°, and to institute a short series of experiments, to determine the nature of the extinction of life in the batrachia, which takes place so suddenly in these circumstances. My experiments upon this point must therefore be regarded as only so far connected with those of M. Edwards, as the influence of that temperature may be deemed similar to that of 108°. Ulterior experiments upon the mere muscular and nervous fibre, appear however, strictly to establish the identity of their operation.

An animal of the order batrachia, as the frog, the toad, the salamander, if plunged into water heated to 120°, first struggles violently, then experiences convulsive movements, and then promptly dies, whilst the limbs become exceedingly and permanently rigid. After apparent death, all sensibility and motion having ceased, the heart is found to beat for a considerable time.

If the head only be placed under water of 120° the animal struggles, but soon ceases to feel or to move; there are, however, no convulsions, and the limbs do not become rigid. The heart continues to beat.

If the spine as well as the limbs be plunged under the water, convulsions are superadded to the other phenomena.

If one of the limbs of a frog recently dead be separated, and placed in water of 120°, it is soon seen to stiffen exactly as in the case in which the whole animal was placed under the water. If the whole posterior extremity be put into the water, the toes are first flexed by the action of the fine muscles situated along their sides, these being most superficial and first impressed by the increased temperature; shortly afterwards the toes are opened and gradually extended by the action of the more powerful muscles, more deeply situated along the leg and thigh, as these, in their turn become affected by the heart.

From these experiments it was obvious that water of the temperature of 120° Fahrenheit acts upon the batrachia in at least two modes: the first action is exerted upon the nervous system, inducing insensibility when the brain is submitted to its influence, and convulsion when the spine is exposed to its agency; the second action is exerted upon the muscular system, giving rise to rigidity.

It became an object of some interest to separate and isolate these two modes of action. For this purpose, the femoral nerve was carefully separated from the other tissues of the thigh, and placed alone in the water: a muscle was next removed, and placed alone in the water; it immediately contracted to nearly four-fifths of its former length, and remained rigid. The nerve, which, when irritated before, induced contractions in the muscles in the limb, had now lost all its power and influence when punctured or pinched very severely. The muscle was alike incapable of being irritated by any external agent.

It was plain, therefore, from these experiments, that water of the temperature of 120° Fahrenheit, acts upon the nervous and muscular system of the batrachia. An animal of this order placed in water of that temperature, has its power of feeling and of motion then doubly annihilated; the deadly influence of this agent is plainly positive; yet it does not affect the heart. It is also too prompt to be regarded as mere asphyxia. The batrachia thus benumbed and stiffened, present the singular phenomenon of an animal dead to animal life, and maintaining a sort of vegetative existence only. The effect of water of 120° upon the muscular system of the batrachia, could not fail to attract a more particular attention. It was an interesting point to determine whether the whole of the muscular system, and especially that of organic life, were alike susceptible of its agency. It has been observed that the heart did not cease to act. But the death of the animal was so prompt, that I imagined that the temperature might not have penetrated to this organ, during the short period during which it was retained under the water. I therefore removed the heart, and placed it alone in the water of 120°. It gradually contracted, became pale and remained rigid; during these changes, a stream of blood issued from its cavity, and descended to the bottom of the vessel in which the experiment was performed.

It was thus proved that the muscles of organic life were equally susceptible with those of animal life, of the contractile influence of water of the temperature of 120°. It next became a question whether this influence of the water upon muscles might not become a test of muscular fibre in organs supposed to be muscular, but in which the point of muscularity is not definitively established. This question required very nice experiments.

Skin, artery, vein, and nerve, were placed with a similar portion of muscular fibre upon a plate of glass, in such a manner that any change in their length would be at once observed; the glass was then placed in water of the temperature of 120°. being very gradually and carefully introduced beneath its surface. The muscle contracted, but no change was observable in any of the other textures.

It was obvious, however, that there might be contraction in the circular fibres of the artery or vein, although none was observed in their length. It was interesting therefore to ascertain whether the form of the vessels viewed under the microscope in their transverse sections, would be altered. I have tried many experiments of this kind: but I must confess that hitherto none have been satisfactory. It still remained to determine whether the temperature of 108°. Fahrenheit, and other lower temperatures, would have the same influence upon the muscular fibre as that of 120°. I ascertained by repeated experiments that this influence is quite distinct at a temperature below 90°; still more obvious at 98°; and very prompt at 108°.— It was a singular reflection that if the textures of the batrachia could be for one minute bathed with human blood at its own temperature, the effect would be instant death to animals in many other points of view so tenacious of life.

I have ascertained that the muscles of the warm blooded animals are also contracted by a temperature above that of blood heat.

The carotid artery of a dog, from being loose and flaccid, becomes contracted in diameter and rigidly cylindrical, if placed in water of 120° Fahrenheit.—The further investigations which these facts suggest are, however, reserved for a future opportunity.

RECAPITULATION.

The points to which the attention of the scientific physician is particularly called in the preceding Essay, are:

1. The distinction between the ultimate minute arteries, the true capillaries, and the first roots and minute trunks of the veins;

2. The successive divisions of the minute arteries, the continual conjunctions and redivisions of the capillaries, and the successive conjunctions and occasional anastomoses of the veins;

3. The characteristic rapid flow of the blood along the arteries, and its retarded flow along the capillaries and veins;

4. The singular differences in the form and distribution of these vessels in the systemic and pulmonary systems; especially,

5. The more abrupt divisions of the arteries, the

more crowded number of the capillaries, and the abrupt formation of the veins, in the latter;

6. The extensive power of the heart in the circulation, the irritability of the arteries, the want of evidence of irritability in the true capillaries, and the effect of the respiratory and other muscular motions upon the course of the blood along the veins;

7. The doubt whether the true capillaries be real vessels or mere canals;

8. The temporary independence of the action of the heart and of the minute and capillary circulation, of the brain and the medulla oblongata and spinalis;

9. The power of the heart to continue the circulation in the minute and capillary vessels, after its entire removal from the body, in opposition to the opinion of Legallois;

10. The independence of the circulation of respiration and of that part of the medulla on which respiration depends, in opposition to the opinion of M. Flourens;

11. The independence of the capillary circulation of a part, upon that part of the spinal marrow from which it derives its nerves, in opposition to

the opinion of Legallois and the original opinion of M. Flourens;

12. The extraordinary difference of removing the brain and medullæ, at once, and in successive portions at distinct intervals;

13. The erroneous mode of explanation of this fact, given by Legallois; another suggested;

14. The temporary independence of the circulation in the minute and capillary vessels, of the entire nervous masses, brain, medullæ, and ganglia;

15. The effect of opium and alcohol upon the batrachia;

16. The effect of alcohol applied to the brain and spinal marrow, upon the action of the heart and the circulation;

17. The effect of crushing the brain and spinal marrow; compared with

18. The effect of crushing other organs or parts, upon the circulation;

19. The general sympathy of these different organs proved by these experiments; and

20. The want of any physiological deduction as to the natural functions of the parts themselves individually;

21. The effects of irritants applied to the web, upon the vessels which pass between its membranes;

22. The impossibility of forming any deduction from this experiment, upon the nature and function of the true capillaries;

23. The singular phenomenon of a caudal heart or ventricle in the eel;

24. The test of muscular structure afforded by water of temperatures moderately higher than that of the blood.

The history of opinion on the subjects of this Essay, is as follows:

1. There is no accurate account of the *Anatomy* of the minute and capillary vessels; the sketch of the pulmonary vessels given by Malpighi, is, however, a literary curiosity, and highly interesting, considering its early date;

2. The circulation of the blood was first amply proved from anatomy and experiment by Harvey;

3. Harvey, Haller, and Spallanzani, alike erred in denying a muscular power to the arteries;

4. Bichat doubly erred, 1. by denying the

muscular power to the arteries, and 2. by ascribing a power to the capillaries of which there is hitherto no proof;

5. Hunter seems first to have had clear views of the muscular power of the arteries;

6. The proof of the irritability of the arteries was still deficient until the discovery of an artery which actually pulsates independently of the heart, in some of the batrachia;

7. The influence of atmospheric pressure in aiding the circulation in the veins, was clearly suggested by Huxham, but actually proved by experiment, by Dr. Barry;

8. The opinion of Haller, in regard to the irritability of the muscular fibre, is still, under certain limitations, the true one;

9. The voluntary and involuntary muscles alike retain their irritability for a time, after their communication with the nervous system is cut off; both gradually lose it;

10. The experiment of removing the brain and spinal marrow, and of watching the effect on the heart and capillary circulation, belongs to a former day, and especially to Whytt and Spallanzani;

11. The repetitions of this experiment by Legallois, Dr. Philip, M. Flourens, and M. Brachet are, in my opinion, less satisfactory than the original experiments of Whytt and Spallanzani, having occupied less time, and consequently afforded less scope for observation ;

12. Nothing appears to have been added to the original experiments, except the important fact of the difference between removing the brain and spinal marrow at once, and by portions at distant intervals, a fact discovered by Legallois ;

13. On the other hand, some of the opinions of the more modern experimenters appear to me to be unfounded ; for example—

14. (1.) The opinion of Legallois, that to destroy a portion of the spinal marrow annihilates the circulation in the parts which derive their nerves from it ; and

15. (2.) That of M. Flourens, that the circulation depends upon that part of the medulla on which respiration depends.

EXPLANATION OF THE PLATES.

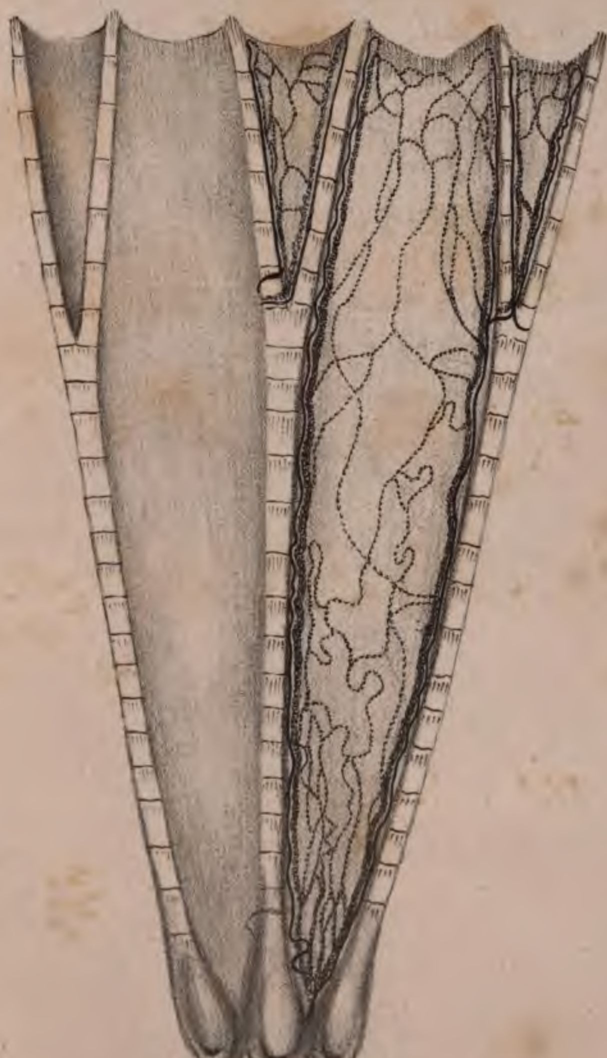
EXPLANATION OF PLATE I.

THE Figure in this Plate represents the distribution of the vessels in the tail of the stickle-back.

The arteries run immediately along the ray, giving off a few capillary vessels in its course; where the ray divides, the artery gives off a branch to supply the new space formed by this division; at the extremity of the ray, the artery turns and assumes the character of a vein.

The vein pursues a course more distant from the ray than the artery, and receives the scattered capillaries from the adjacent membrane. Near the origin of the rays, the capillaries join and form several shorter veins.

Pl. I.



Drawn & lith. by J. Hawkins

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EXPLANATION OF PLATE II.

This Plate represents the course of the minute arteries and veins in the web of the frog.

The arteries are seen as small black lines which merely divide into smaller branches.

The veins are seen in nearly equal number, more varied and tortuous in their course, and presenting frequent anastomoses.

The arrows denote the directions in which the globules of blood flow along these anastomosing branches.

Pl.II.

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EXPLANATION OF PLATE III.

This Plate represents the minuter branches and sub-divisions of the arteries of the web; their final divisions into capillaries in which the globules become distinct; and the union of these so as to form the roots of veins.

The arteries subdivide into smaller branches. The capillaries continually unite and re-divide, retaining a uniform size and a uniform velocity of circulation; the various roots unite successively, forming larger and larger veins, and anastomose occasionally, still preserving the velocity of the capillary circulation.

Figures 2. and 3. represent the two layers of capillaries. In figure 2, the blood in the upper layer has been rendered stagnant by the application of alcohol. In figure 3, the lower layer of capillaries is affected by the spirit.

Pl. III.

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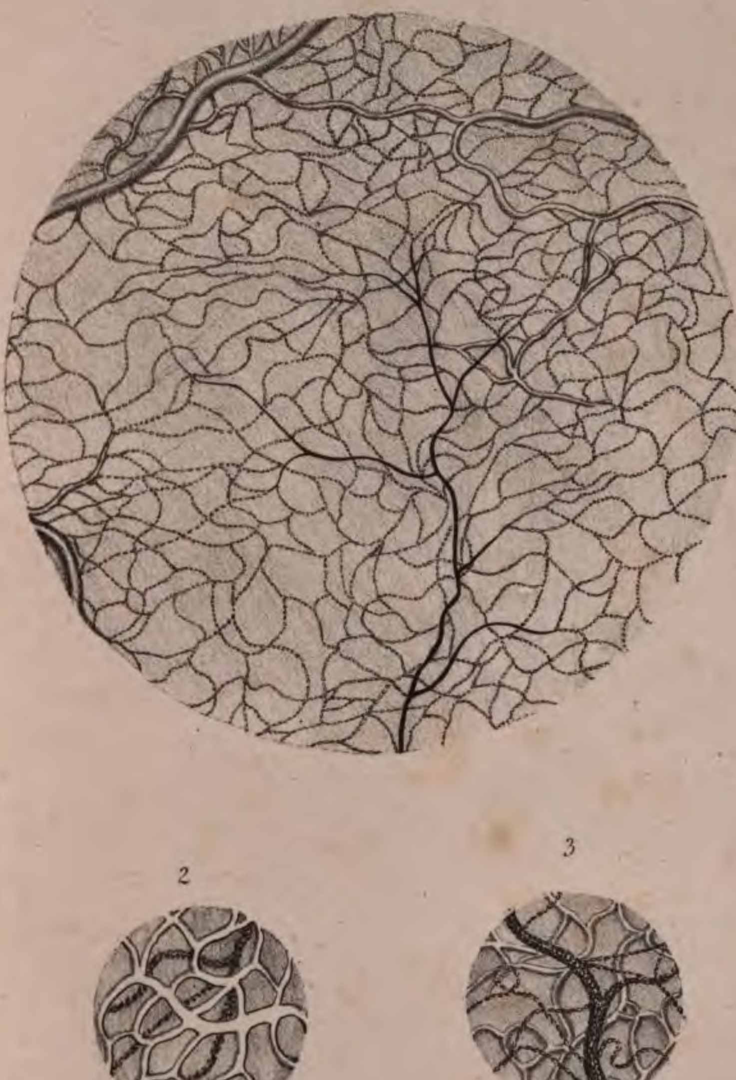

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EXPLANATION OF PLATE IV.

In this Plate the large arteries and veins which pass to and from the intestine are represented.

The intermediate spaces are occupied by a few scattered capillary vessels.

Figures 2. and 3. represent the maculæ seen in the course of the arteries and veins in some spotted animals.

Pl. IV

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EXPLANATION OF PLATE V.

This Plate pourtrays the peculiar symmetry, parallelism, or antagonism of the arteries and veins in the lung of the salamander. Its beauty is only discovered by a very attentive examination.

The minute arteries and veins are often simply parallel. The terminal artery frequently passes into the angle made by two venous roots, and sometimes into the space formed by a curved vein.

This disposition is seen even at the very tip of the lung: so that in no part does the artery terminate immediately in the vein.

Pl. V.

1

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EXPLANATION OF PLATE VI.

This Plate beautifully pourtrays the cellular structure of the lung, and the peculiar distribution of its principal arteries along the external surface of the lung, at the roots of the internal meshes. The course of the artery is frequently obscured by the projecting meshes; it is thus marked by dotted lines.

Pl.VI.

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EXPLANATION OF PLATE VII.

In this Plate are seen the singular distribution of the principal veins along the internal borders of the internal meshes of the lung of the frog. The artery is frequently obscured by the intervening projecting mesh; but the vein is readily traced throughout its whole course.

Pl.VII

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EXPLANATION OF PLATE VIII.

This Plate admirably pourtrays the beautiful disposition of the arteries, veins, and intervening capillaries, as seen on the surface of the lung of the toad, highly magnified.

The arrows denote the course of the blood, and distinguish the arteries and veins, which are perfectly similar in form and character.

Pl.VIII.

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EXPLANATION OF PLATE IX.

This Plate displays the course of the artery seen to pulsate after the removal of the heart, in the frog and toad.

This pulsation is seen above and below the transverse process. Viewed under the microscope, the artery is observed to become straighter and paler, whilst the globules of blood contained in the branch given off to the right, are perceived to oscillate.

Another pulsating artery is represented situated higher up. Not being so curved, or so bound down, its pulsations are not nearly so obvious as those of the artery which passes under the transverse process.

Pl. IX

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EXPLANATION OF PLATE X.

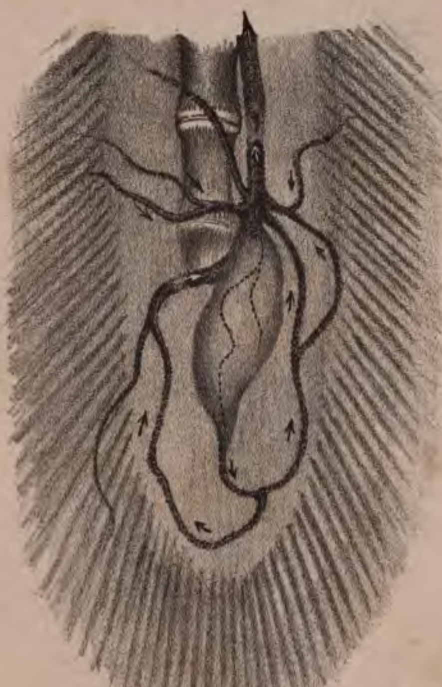
The last Plate represents the caudal heart or ventricle seen at the extremity of the eel.

It is a palish sack. The distribution of the adjacent vessels, and the course of the blood in them, are distinctly represented.

In smaller eels, another vessel is seen descending near the spine.

The minute anatomy and connexions of this singular organ still require to be investigated.

Pl.X.



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