DOCTRINES

OF THE

CIRCULATION.

A HISTORY OF PHYSIOLOGICAL OPINION AND DISCOVERY, IN REGARD TO THE CIRCULATION OF THE BLOOD.

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INTRODUCTION.

If any apology were offered for the appearance of this volume, it would be that the circulation of the blood is of such commanding importance, as a physiological function, that the interest involved in the history of its discovery is not easily exhausted. In some respects this interest increases with the examination of the subject. At the present day the circulation of the blood is so familiar to us, and so easily demonstrated by methods accessible to all, that we regard it as one of the simplest facts in physiological science; and we are apt to look with surprise at the mental blindness of the older physiologists who did not know it, or who were reluctant to acknowledge its truth when first announced. But these men were neither ignorant nor dull. They were conversant with everything then known in physiology. Many of them were laborious, original investigators, who contributed not a little to the advancement of science, and who were equal, in learning and capacity, to any of the celebrities of modern times. It becomes apparent, in reading their works, that the knowledge of the circulation of the blood was no easy acquisition. In the dead body, the blood in the bloodvessels was as stationary as the bile in the gall-bladder; and its movement during life was indicated by no external sign. Like many other things of a similar kind, when once fully demonstrated it seemed plain enough; but until then it was one of the secrets of nature, not to be unveiled except with much labor and after many trials.

Differences of this sort, between one period and another, are often accompanied by changes in medical nomenclature. In the gradual progress of thought and discussion, the opinions of medical writers are so modified that after a time even their language becomes unintelligible, unless we remember the state of knowledge existing when they wrote. A student of anatomy, for example, in the present century, would be hopelessly confused by the contradictory appellations of the "vena arteriosa" and "arteria venosa," which once expressed so well the character and relations of the pulmonary artery and the pulmonary vein. The phrases, "vital spirits" and "animal spirits," would convey no meaning whatever in a physiological treatise of to-day; and yet they formerly represented ideas, perhaps as distinct and useful as those which we now designate by the terms "reflex action" or "animal ferment."

This modification of phraseology, due to the progressive changes in medical knowledge, may sometimes serve as a guide in exploring the literature of the past. It is often difficult to appreciate the importance or even the significance of a former discovery, unless we know the condition of medicine in the period immediately preceding. The obscurities and misconceptions which then existed may have long ago disappeared; but they were none the less real for the writers of that time, and they would still exist for us, had it not been for the successful work of our predecessors. This must always be kept in view, in attempting to follow the development of a particular doctrine. Harvey's book, *De Motu Cordis et Sanguinis*, contains many things which to the modern reader are by no means easy of comprehension. The difficulties which he encountered, the doubts which perplexed him, and the incredulities which he had to meet, belong to a set of ideas which have now passed into oblivion. To understand them, we must refer from Harvey to Caesalpinus and Colombo and Vesalius; from them to the earlier writers of the renaissance; and from them, of course, to Galen and Herophilus and Aristotle. In this way, the student of physiological history is led back from one century to another, and his interest excited in periods successively remote. The labor required for such an investigation turns out, therefore, to be greater than at first supposed; but it is fully compensated by the connected view which it affords of the progress of science, and it enhances the value of our present knowledge by showing the obstacles and uncertainties which impeded its acquisition.

DOCTRINES

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CHAPTER I.

ARISTOTLE.

If the period represented by Aristotle is sometimes called the dawn of natural science, this must be understood only in a comparative sense, and as applied to an age seen through the medium of remote antiquity. It was a period of great intellectual activity, not only in the abstruse field of metaphysical philosophy, but also in the direct investigation of nature. In this department Aristotle was pre-eminent; and it would be impossible to form an estimate of the state of physiological knowledge at that time, without relying principally upon his works. A large part of his information was, no doubt, original; but he also alludes to many facts of a more strictly medical interest, which he probably acquired from earlier or contemporaneous sources. He was the son of a physician,* and may have inherited in this way his taste for natural history

* Nikomachus, physician to Amyntas, king of Macedonia and the father of Philip.

and his predilection for scientific methods. His opportunities were unusually great, and enabled him to follow successfully the natural bent of his disposition. All writers agree that he had large resources at his command, which he used liberally in the purchase of books and otherwise; and he is said to have received, from the treasury of Alexander, funds to the amount of 800 talents ($800,000),* for making his collections and prosecuting his researches in natural history.

The works in which Aristotle treats of anatomical and physiological matters are those on the Natural History of Animals, on the Parts of Animals, on Animal Locomotion, on Respiration, on the Pneuma or Spiritus, and on Generation. There was also a special treatise on anatomy, which is however one of his lost books. Some of the above contain many passages which are obscure; either from our inability to comprehend allusions which were understood at the time, or from imperfect restoration of injured portions.† But they present a large and varied collection of facts relating to the structure and action of the animal body, a comparative view of different functions, and a description of the habits and modes of life in different animals. A prevailing feature throughout is the attention paid to the final object or purpose of an organ and its function; this idea being generally inseparable from the consideration of its structure and immediate operation.

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* This statement rests on the authority of Athenæus, a Greek writer of the third century after Christ, some of whose works are still in existence.

† A large part of Aristotle's works were seriously damaged, from neglect, after his death and before they were purchased for the library of Apellikon.

The physiological relation between lungs and gills, the air-breathing and mammalian character of whales, dolphins, and other cetacea, the distinction between the fully viviparous mammalians and the cartilaginous fishes, which produce living young from partly developed eggs in their interior, are all clearly and accurately discussed (1). Neither of these works is arranged on a plan like that which would now be adopted for a treatise on the same subject; but they are full of interest from an historical point of view, and some of their descriptions are regarded by naturalists as hardly surpassed by any which have appeared since.

In Aristotle's conception of the sanguiferous system, the *heart* is the central organ and prime mover of the whole; but in a different sense from that in which it is now understood. For us the heart is a sac-shaped muscle, causing by its contractions the physical propulsion of the blood through the vascular system. For Aristotle it was the seat of vitality; in which the blood received its final elaboration and its impregnation with animal heat (2). The heart was, therefore, the immediate source of the blood; not because it propelled this fluid in a moving current, but because it united its ingredients in due combination and endowed them with the stimulus of life. The whole mass of the blood, thus originating from the heart, was contained in the bloodvessels as in a vase; since, as he expresses it, every liquid must have a vessel, or vase, to contain it. This idea is still traceable in the name used at present; for the term blood-*vessel* does not necessarily imply a tubular form, nor any movement of the contained fluids. The bloodvessels extended, by their branches and ramifications, throughout the body, in order that the blood, as the material of nutrition, might come in contact with every part.

With Aristotle there is no radical distinction between arteries and veins. The term φλέψ, usually translated "vein," means simply a bloodvessel; and all the bloodvessels (φλέβες) contain blood of the same quality. The only difference between them is in their size, the structure of their coats, and the regions which they occupy. The Great Bloodvessel (ἡ μεγάλη φλέψ) is the vena cava, which, with its branches and ramifications, has thin and flexible walls, and is situated in front and on the right side. The aorta (ἀορτή) is a bloodvessel of fibrous texture (νευρώδης ἐστὶ φλέψ), smaller in size, and situated behind and toward the left. Its terminal ramifications are altogether fibrous, their cavities being obliterated (3).

"The body of the heart is central in position, dense in structure, hollow, and filled with blood. Central, as the point of origin for the bloodvessels; hollow, for containing the blood in its cavity; and dense, for the protection and preservation of the animal heat. It is the only part of the body where we find blood otherwise than in bloodvessels; in every other organ this fluid is enclosed in bloodvessels. There is good reason for this difference; since the blood is distributed from the heart to the bloodvessels, but is not brought into the heart from elsewhere. It is the source and fountain of the blood, and its prime receptacle" (4).

"Animation and the possession of vitality, as already said, are necessarily associated with heat. The process of digestion, through which the nourishment of animals is accomplished, cannot be carried on without heat as well as vitality; for everything is elaborated by fire. Consequently in whatever region of the body, and in whatever organ, the principle of heat is primarily located, there also must be the original vital principle of nutrition. . . . . In the bloodless animals this organ has no distinct name; but in those provided with blood, it is the heart. The nutriment from which the tissues and organs are produced is the substance of the blood; and the bloodvessels must have the same point of origin with the blood, since they exist only for the sake of containing it, as its vase or receptacle. Now the origin of the bloodvessels, in animals provided with blood, is the heart; for, as we learn from dissections, they all have attachments to this organ without passing through its substance. The other active functions of life, for reasons to be explained hereafter, cannot go on without that of nutrition; nor that of nutrition without the fire of nature (animal heat). For nature kindles the nutritive function in this fire" (5).

To estimate fairly the theory of the blood and bloodvessels in any physiological system, we must also take into account the functions of nutrition and alimentation. The character of the blood, as the *general nutritive fluid* of the body, is fully recognized in Aristotle's doctrine. With its elements originally derived from the food, but elaborated and perfected in the heart, it contains all the ingredients requisite for the nourishment of the animal frame. Disseminated through the body by the vascular system it penetrates the entire structure; and by its exudation or transfusion, in due proportion, it supplies everywhere the materials of growth and secretion. The parenchymatous organs are thus, in a manner, deposits from the blood which has transuded through the vessels, as the perspiration or the saliva is a transudation of its watery parts. This final consumption or assimilation of the blood, in local nutrition, is plainly described and illustrated; the loss incurred at the periphery being made good at the heart, by the formation of new blood from the materials of the food. There is no movement of the blood, in a mass, from the heart outward through the vessels; but it is unceasingly renewed by consumption at one end of the vascular system and an equivalent supply at the other. How rapid this change in the substance of the blood may be, is not estimated in definite terms; but it is implied that it corresponds with the daily amount of the products of digestion (6).

The function of *alimentation*, according to Aristotle, consists of two successive acts; first, the digestion of the food; and secondly, the absorption of digested nutriment from the alimentary canal.

Digestion is a process of coction (πέψις); that is, a modification of the nutritive ingredients by the action of heat. The different portions of the alimentary canal are well described, with their varieties in different animals; and their functions are indicated sometimes with remarkable clearness. The mastication of the food, for example, in the mouth, does not accomplish any part of its real digestion; but only its physical disintegration, by which it becomes more amenable to the digestive action of the stomach (7). The main divisions of the alimentary canal in the abdomen are: 1st, the stomach or upper cavity, in which the masticated food is received; 2d, the small intestine, where its digestion and separation go on; and 3d, the colon or lower cavity, in which it becomes exhausted and feculent, until at last only its surperfluous parts remain, under the form of excrement (8). Thus the entire act of digestion, in the alimentary canal, consists of a molecular change in the nutritive ingredients of the food, and their separation from the unnutritious or feculent portions. But as the latter are the only substances remaining in the lower part of the intestine, it is plain that the former must have passed out of the alimentary canal, in the meantime, by transudation through its walls. The manner in which this is accomplished forms a second and very interesting part of the function of alimentation.

The digested nutriment, according to Aristotle, is absorbed from the alimentary canal by the mesenteric bloodvessels. The act of digestion thus far is only preliminary. The materials so produced are mingled with the blood, where they undergo still further changes until their final elaboration in the heart. Aristotle employs, in treating this part of the subject, two striking similitudes. He speaks of the body in general taking its nourishment from the stomach and bowels, "as out of a manger;" as if the more important phases of its modification were to take place farther on. He has also a favorite comparison between the contents of the alimentary canal, as a source of nourishment for animals, and the earth, as a source of nourishment for plants. The natural heat of the earth, he says, brings the ingredients of the soil into the required condition, so that they need no further change to fit them for absorption; while the mixture of digested and undigested food in the intestine is a sort of soil, from which the nutritive portions are taken up by the bloodvessels of the mesentery. This comparison, which is not wanting in aptitude, is sometimes made by modern writers, who speak of the valvulæ conniventes and villi of the intestine, imbedded in the nutritious magma, like the rootlets of a plant; often, undoubtedly, without any suspicion that the idea is as old as Aristotle.

"As the mouth and the part contiguous with it, known as the œsophagus, give passage for the imperfectly prepared food as far as the stomach, so there must be other means by which the entire body may get its nourishment out of the stomach and bowels as from a manger. Plants draw their nutriment ready formed from the soil, and consequently they have no superfluous or residual matters; for the soil, with its inherent warmth, serves them in place of a stomach. Nearly all animals, on the other hand, especially those provided with limbs, have within themselves a sort of soil, namely, the cavity of the stomach, from which they take up their nourishment into some other organ, as plants take up theirs by their roots until its subsequent digestion is complete" (9).

"The mesentery, so-called, is a membrane stretching continuously from along the intestines to the vena cava and aorta, full of numerous and closely-set blood-vessels, which also extend from the intestines to the vena cava and aorta. In its growth and formation this membrane is, of course, similar to other parts; the purpose of its existence, in animals provided with blood, being evident on examination. Since animals must needs be supplied with food, from which again is produced the perfected aliment for distribution to the organs (which perfected aliment has no special name in bloodless animals, but in the others is called blood), there must be some way for its conveyance, as if by roots, from the alimentary canal into the bloodvessels. While plants accordingly have roots fixed in the soil, in animals the stomach and bowels furnish a kind of soil, from which their nourishment is to be drawn; and for that is provided the structure of the mesentery, with its bloodvessels like so many roots" (10).

It is plain, accordingly, that the products of digestion are considered as absorbed from the intestine into the bloodvessels, to be there mingled with the blood; and that, after having passed into the vascular system, they receive their complete transformation or sanguification in the cavity of the heart. It seems natural to infer from such a description the existence of a vascular current, proceeding from the intestines toward the heart, to deliver into that organ the materials absorbed in digestion. But this was not the idea of Aristotle. Notwithstanding his unmistakable recognition of absorption by bloodvessels from the intestine, there is no evidence that he imagined anything like a physical movement of the blood from thence toward the heart. For him the mesenteric vessels absorbed the digested fluids, either by endosmosis or by the aid of minute orifices; or, to use his own expression, as the roots of a plant absorb materials from the soil. By a continuance of this process the change in the ingredients of the blood would at last be perceptible in the heart, where they are subjected to a further influence, to be then disseminated in a similar way throughout the vascular system.

To a great extent, this is what really takes place. The local circulation of the blood, that is, its continuous movement through the capillaries of the mucous membrane, and from them toward the heart, is not essential to the imbibition or endosmosis of fluids from the intestine; it only facilitates this action and increases its rapidity, by the incessant renovation of the absorbing medium. Aristotle must, therefore, have regarded the absorption of nutriment by the mesenteric bloodvessels as a much slower process than we now know it to be; but he nevertheless believed it to take place, and considered it as the route by which the digested material found its way into the general system.

In Aristotle's anatomy of the lungs we are struck by the unexpected use of a term which we are accustomed to regard as designating a bloodvessel. With him the word ἀρτηρία (artery or air-tube) signifies the trachea. It is the passage through which air is introduced into the chest, and which, by its divisions and ramifications, disseminates the inspired breath throughout the pulmonary tissue. Its cartilaginous structure, the angular division of its branches, and the intermingling of air-passages and bloodvessels in the substance of the lung, are all accurately described, so far as they could be determined by the anatomical methods then in use. It is an additional evidence that the division of the vascular system into so-called arteries and veins had no existence in the physiology of the period.

"The trachea (ἡ ἀρτηρία), in all animals having this organ, is situated in front of the œsophagus; and it is present in all animals with lungs. It is cartilaginous in texture, and has but little blood, though there are many slender bloodvessels surrounding it. Its upper extremity lies toward the mouth, below the orifice of communication with the nares, by which liquids, when ejected in drinking, find their way out through the nostrils. Between the openings (of the mouth and nostrils), it has the so-called *epiglottis*, which is attached to the posterior part of the tongue, and can be applied over the orifice of the trachea (τῆς ἀρτηρίας), toward the mouth. In the other direction the trachea passes down between the lungs, and there divides, running to each of the pulmonary lobes. . . . . . If the trachea be inflated (φυσωμένης δὲ τῆς ἀρτηρίας), it delivers the air into the pulmonary cavities; and in these cavities there are cartilaginous septa, joined at an acute angle, and forming, in this way, openings or passages extending throughout the lung, and constantly diminishing in size, from greater to less. . . . . The trachea (ἡ ἀρτηρία) has therefore the structure above described. It serves only for the ingress and egress of the breath, not for the admission of solids or liquids; and any such matters, if they gain entrance into it, cause continued distress until they are discharged" (11).

The foregoing passage cannot leave any question that by "artery" Aristotle means the trachea. This use of the term was not peculiar to him, as it had been employed in the same sense, three-quarters of a century before, by Hippocrates (12); and it was, no doubt, the common designation for the trachea, or windpipe, at that time.

The remaining anatomical feature to be noticed in this connection relates to the pulmonary artery and the pulmonary vein. Aristotle has little to say about these vessels, but it is plain that he does not regard them as bloodvessels,—at least not in the same sense with the other members of the vascular system. He speaks of them as "channels" (πόροι), reaching from the right and left cavities of the heart to the lung, into which their branches penetrate. Their office is to receive from the lungs the "spiritus," or πνεῦμα, which is thus conveyed to the heart, and there mingled with the blood. It is not easy to say precisely what this πνεῦμα may be, but it certainly is not the inspired air absorbed in mass from the pulmonary passages. It seems to be rather a vaporous ingredient, extracted from the breath and appropriated by the blood in the process of sanguification. At all events, the pulmonary artery and vein, which serve for its conveyance, are evidently regarded as distinct in character and function from the bloodvessels in general, which are expressly described under a separate title as branches of the vena cava and aorta.

"For there are channels extending from the heart to the lung which divide in the same way as the trachea, their branches running throughout the lung in company with those of the trachea, but above them. They have no open communication with the latter, but through their mutual contact they take in the spiritus, and convey it to the heart. One of them leads into the right cavity (of the heart), the other into the left. As for the vena cava and the aorta, we shall speak of them later on" (13).

Perhaps the most important phenomenon to be accounted for in the physiology of the sanguiferous system is that of the cardiac and vascular *pulsation;* and this was regarded by Aristotle as taking place in a manner totally different from that which is admitted now. In his view it was caused by an expansion of the blood within the heart and bloodvessels.

"The cardiac pulsation, on the other hand, which is always going on without interruption, is analogous to that of inflammatory swellings, where it is accompanied by pain owing to the abnormal changes going on in the blood, and which finally terminate in suppuration. This morbid process resembles an ebullition, in which the boiling liquids are inflated with heat, and thrown up by their expansion. In inflammatory swellings, where transpiration cannot take place, and the liquids become thickened, it results in their decomposition; while a boiling liquid escapes from the containing vessel.

"In the heart there is a continual accession of liquids from the nourishment; and their expansion by heat extending to the walls of the organ causes its pulsation. This goes on continually. For there is an incessant ingress of fluids to supply the substance of the blood elaborated in the interior of the heart. This is evident from the manner of its earliest formation in the embryo; for the heart may be seen, already containing blood, before the bloodvessels are yet distinctly marked out. The pulsation, accordingly, is greater in the young than in the old, because in the young the exhalation or expansion from heat is more active. All the bloodvessels moreover (φλέβες πᾶσαι) pulsate, and simultaneously with each other, since they are attached to the heart, which is itself in constant motion; consequently the bloodvessels also move, all together, and at the same time with the heart" (14).

The dominant idea in the physiology of Aristotle is the idea of innate vitality operating through the agency of animal heat. In the ancient theory of physics the so-called "fire," or principle of heat, was one of the material elements; the most attenuated and ethereal of all, and at the same time the most efficient. It represented the immediate cause of all chemical and molecular activity. The external phenomenon of sensible warmth was only one of its manifestations; it also produced a variety of other results. It converted solids into liquids, or liquids into vapors. It caused the ebullition of water, and the fermentation of organic mixtures; and it excited, in the vegetable and animal worlds, the internal movement of germination and growth.

This is the view taken by Aristotle. "There are some," he says, "who do not admit heat to be the agency that works in material substances; because, as they say, fire has only one kind of force or action, and that a destructive one. But this is a mistake. Even in inanimate things, fire does not always produce the same effect; some of them it thickens, some it relaxes and liquifies, and some it changes to a solid condition. And the natural fire of living creatures we should study in the same way as we do that of artificial origin. In the mechanical arts, fire produces a different effect as used by the goldsmith, the brass-worker, the joiner, or the cook. Perhaps it would be better to say that its effects depend rather on the arts themselves than on the kind of fire employed. The arts use it as their instrument; to soften, liquefy, or desiccate, and sometimes to adjust or modify. The various natures in the living body (αἱ φύσεις) do the same thing, and so differ from each other in their action. It would be absurd, therefore, to judge from external appearances. Whether the act of heating and combustion consist in a decomposition or rarefaction, or whatever it may be, its effect will vary according to the hands by which it is used. Now the arts use it as an instrument only, but nature also as material"* (15).

* That is, combines it with the other ingredients of an animal tissue or fluid, so that this tissue or fluid shall itself have the active force or

With Aristotle, accordingly, the vital heat of the animal organism acts in many ways. By its aid the form of the embryo is first sketched out in the egg during incubation; and it produces, in the fully formed animal, the manifold changes of digestion, assimilation, and nutrition. One of its most striking effects is shown in the cardiac and vascular pulsation. By its increment in the blood, and its combination with the other ingredients of this fluid, the blood is expanded in a manner analogous to that of boiling water, distending by its impulse the heart and bloodvessels. According to this doctrine, it is the blood which palpitates in the vascular system, from the internal force of its own vital heat; and the pulsation of the heart, as well as that of the bloodvessels, is a passive effect of this cause. There is no difference in this respect between what we call the veins and the arteries; for they are all bloodvessels, containing the same kind of blood, and having their common origin in the heart. The expansion of the bloodvessels, moreover, is everywhere synchronous with that of the heart. The formation or elaboration of the blood, and its impregnation with the vital heat, take place in the cardiac cavities; but the stimulus thus produced is at once communicated to the blood throughout the body, and all the bloodvessels consequently pulsate simultaneously with each other and with the heart.*

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power of heat, and can exercise it on other substances. As if we were to say that the *pepsine*, dissolved in the gastric juice, imparts to this fluid its catalytic action on albuminous matters.

* This seems, perhaps, a great error. But Aristotle, and others of his time, naturally regarded the stroke of the heart against the walls of the chest as due to its dilatation; and this stroke or pulsation is really synchronous with the arterial expansion at the wrist and elsewhere. It

The phenomena of *respiration*, according to Aristotle, are in some respects of a similar character, and its purpose as a function is closely allied to the foregoing. A full supply of heat is indispensable for the vital operations. But, as in the mechanical arts, it must not exceed a certain intensity; otherwise it becomes a source of disturbance, causing abnormal changes in the organs. Respiration provides against this difficulty, and confines the animal heat within physiological limits. The cool air, introduced from without, comes in contact, in the pulmonary passages, with the surrounding bloodvessels, and reaches through them the source of heat in the blood. It takes away a portion of this heat, becoming itself consequently warmed; and it is then discharged by expiration to make way for a fresh supply. The cooling influence is thus repeated at short intervals, and is even regulated in a sort of automatic way, according to the demands of the system. For when the bodily temperature rises too high, either from unusual warmth of the atmosphere or from accumulation of internal heat, respiration is accelerated and the normal balance restored.

This is the main object of the function of respiration. It is frequently alluded to by Aristotle, and is fully described in his special treatise on that subject. "As for the reason," he says, "why animals provided with lungs take in air by respiration, and why this function is especially active where the lungs are abundantly supplied with blood, it depends upon the spongy and cancellated texture of the lung, and its excessive

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was only Harvey who learned that the external impulse of the heart represents its contraction and not its dilatation. This was his very first discovery, and the basis of all the rest.

vascularity. As this organ is unusually full of blood, and its heat so readily liable to vary in intensity, it needs a rapid cooling influence, and one that can penetrate easily throughout. Air is well adapted for this purpose, since its rarity enables it to disseminate rapidly and carry its cooling influence to every part."

. . . . "The animal organism in all cases requires a cooling influence, on account of the fiery kindling (ἐμπύρωσις) of the principle of life within the heart. In animals with both heart and lungs, this is supplied by the act of inspiration. In fishes, which have a heart but no lungs, the same thing is effected by means of water through the gills" (16).

There is evidence that Aristotle also regarded the inspired air as furnishing to the blood a certain aëriform ingredient, the πνεῦμα, or "spiritus" (page 28), which was important in some way to the vital operations. But his observations on this point are too obscure to admit of a satisfactory interpretation. His doctrine as to the cooling action of the breath, on the other hand, is perfectly distinct, and is consonant morever with the results of modern investigation. The mere fact that the air, as he says, is cool when it enters the lung and warm at its exit, shows that it must have taken away a certain quantity of heat from the internal parts. We know from experiment that this is actually the case; the blood being cooled during its passage through the lung, and its diminution of temperature in these organs amounting sometimes to more than one degree Fahrenheit. If we consider, furthermore, that the vaporization of water from both lungs and skin consumes in twenty-four hours about one-fifth of all the animal heat produced, it is plain that the refrigerating influence of the external atmosphere is of no small value in regulating the animal functions. Respiration has, in addition, a much more important office, namely, that of supplying oxygen to the blood. But this was unknown in ancient times, and had no place in the physiology of the period.

The *mechanism* of respiration, according to Aristotle, is somewhat like that of the cardiac pulsation. The increase of internal heat produces an expansion of the lung; and by this expansion the air is drawn, through the trachea, into the pulmonary cavities. Its heat having been moderated by the contact of the air, the lung again collapses and the breath is expelled. Thus the movements of inspiration and expiration follow each other in regular order, as the tension of the lung is alternately increased by the accumulation of animal heat, and relaxed by its diminution.

"Respiration depends on the growth or augmentation of the animal heat, in which is the principle of nutrition. As the other constituents of the living body require nourishment, so also does this one; and even more than the rest, since it is the cause of nourishment for all. With its increase in quantity it necessarily expands the lung. This organ must be regarded as in structure somewhat like the bellows of a forge; both the lung and the heart having a form not very dissimilar to that."* . . . . . "This seems to be what happens in respiration. The thorax expands because the principle of the organ contained within it does the same. By this expansion the outer air is drawn into

* The ancient "bellows" was a leather bag, made from the entire skin of a goat, or other animal of suitable size.

it as into a bellows, and by its coolness moderates the excess of internal heat. But, as the thorax is expanded with the increase of the internal heat, so must it collapse with its diminution. By this collapse the air is again expelled, being cool at its entrance, but warm at its exit, from contact with the internal heat of the parts; especially in animals with lungs that are highly vascular. For it penetrates into numerous hollow passage-ways in the lung, the bronchial tubes; each of which is accompanied by bloodvessels, making the lung apparently everywhere full of blood. The entrance of air is called inspiration; its discharge, expiration" (17).

There appears to be something like a contradiction in the idea of the lung being expanded by a distension from within, and yet drawing into it the external air, to satisfy a vacuum; because such a distending force would seem likely to oppose, rather than invite, the entrance of anything from without. But this difficulty does not really exist in Aristotle's doctrine. The internal heat which excites the movement of respiration is in the blood contained in the bloodvessels; which are themselves in contact with the bronchial tubes, but outside their cavities. The expansion is, therefore, in the tissues surrounding the pulmonary channels; and it consequently lifts the walls of the thorax without impeding the influx of the air. So long, therefore, as the lungs perform their office, every immoderate increase of heat brings with it its own remedy; for it sets in motion a mechanism which at once introduces cool air in the needed proportion.

It appears, accordingly, that, in the earliest system of physiology known to us, many essential features of the nutritive process were fairly appreciated, although its more important physical conditions were unknown. The blood was regarded as the great nutritive fluid of the body, absorbing new material from the digestive apparatus, and supplying it to the tissues through the medium of the bloodvessels; but without the aid of a physical transportation. There was no outward current through the arteries, and no returning current through the veins; but only a continual renovation of the blood by the act of nutrition, as there might be in any reservoir of fluid constantly drawn upon at one end and fed at the other. The ideas entertained by Aristotle, in regard to the heart and bloodvessels, may therefore be summarized as follows:

I. The heart was an organ for giving to the blood its final elaboration, and for communicating to it the necessary element of vital heat.

II. The perfected blood was received from the heart into the bloodvessels, arteries and veins alike, and brought, by their branches and ramifications, into proximity with the solid tissues, which it nourished by exudation.

III. The pulsation of the heart was a momentary dilatation from expansion of the blood in its cavities; this expansion being produced by the animal heat combining with the ingredients of the blood. The pulsation of the bloodvessels was due to the same cause, and was simultaneous with that of the heart; the impulse originating in the cardiac cavities being at once communicated to the blood in every part.

CHAPTER II.

PRAXAGORAS.

With Praxagoras there appears a new feature in the history of the vascular system; namely, a physiological distinction between the veins and the arteries. Before his time, they were classed together as bloodvessels, distinguished only by the anatomical structure of their coats. They are now separated into two distinct systems, with different functions and designated by different names; that is, the veins containing blood, and the arteries containing air.

Praxagoras, who was a native, and probably a resident, of the island of Cos, opposite the coast of Asia Minor, lived between 300 and 400 years before Christ. He was a man of great eminence in his time, well known throughout the Grecian world, and of high reputation in both scientific and practical medicine. Celsus enumerates him,* in the same category with Hippocrates, Diocles, and Chrysippus, as among those who had exercised the greatest influence on medical art. His original works have long since disappeared, but they are known through quotations or references by Pliny, Rufus Ephesius, Galen, and Cælius Aurelianus; all writers of the first two centuries after Christ. He seems to have made a special study of the fluids of the body, both in health and disease; considering their

* Celsus, De Medicina, Præfatio, Leipzig edition, 1746, p. 3.

alteration or perversion as the cause of many morbid affections. Some of his doctrines in regard to diagnosis and treatment, if correctly reported, were very striking. According to Cælius Aurelianus,* he regarded stercoraceous vomiting as the sign of acute tumor (obstruction) of the intestine; and for its relief, when other manipulations failed, he advised opening the abdomen and dividing the intestine to remove the obstruction; after which the intestine was to be reunited by sutures. If this recommendation were the result of his own experience, it would imply that the modern surgery of the abdominal cavity was not altogether unknown in ancient times.

But the most important innovation of Praxagoras, at least for the vascular system, related to the character and function of the arteries. The change which he introduced into the physiology of these vessels was twofold. In the first place, he observed that the phenomenon of *pulsation*, previously regarded as a common attribute of arteries and veins, really belonged only to the arteries (18). They were consequently seen to differ in this respect from the veins, in which no such movement was perceptible. They were, furthermore, distinguished by the nature of their contents; for, while the veins were still considered as receptacles for the blood, the arteries, according to the new view, contained no blood, nor any liquid material (19), but only an invisible gas or air.

By nearly all writers on the history of medicine the origin of this distinction between veins and arteries is attributed to Praxagoras; although the fact has been

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* De Morbis Acutis, liber iii., cap. xvii.

sometimes called in question, especially by Littré* and Kühn.† The meagreness of our information from original documents leaves, perhaps, some room for doubt; but the weight of evidence, as well as the preponderance of authority, seems to indicate that this doctrine was certainly promulgated at the time of Praxagoras, and in all probability by him, as the anatomist of greatest repute in the period immediately following Aristotle.

It is generally believed that the idea of the vacuity of the arteries was derived from examination of the dead body. At the time of death the blood is mainly expelled from the arterial system, and accumulates in the veins. But when, in the course of dissection, the vessels are cut across, and air admitted to their interior, the flaccid veins still contain the coagulated blood, or collapse, if it be withdrawn; while the elastic arteries resume their original form and appear as empty cylindrical tubes. Under these circumstances, the two sets of vessels are really in the condition described by Praxagoras; the veins containing blood and the arteries containing air. He had found, moreover, that, during life, the veins or bloodvessels are quiescent, while the arteries pulsate; and this action he attributed to the stimulus of their gaseous contents. It is impossible to say with certainty what was the supposed nature of this aëriform fluid in the arterial system; but it seems to have been identical with the so-called *pneuma*, or spiritus, already admitted by Aristotle, which afterward became so important an element in the physiology and pathology of the Alexandrian school. Praxagoras was

* Œuvres Complètes d'Hippocrate, Paris, 1839, tom. i., p. 202.

† Opuscula Academica, Lipsiæ, 1828, vol. ii., p. 136.

the preceptor of Herophilus, one of the most eminent of the Alexandrian anatomists; and he, no doubt, furnished the basis for much of the doctrine developed by his pupil.

The physiology of Praxagoras was plainly an improvement on that of his predecessors; since the important phenomenon of vascular pulsation, attributed until then to all the bloodvessels alike, was referred by him to its true place in the arterial system. But this advance was associated with a singular misconception; inasmuch as the arteries, previously regarded as bloodvessels, were separated from the sanguiferous system, and credited with an unreal function, as the recipients of a hypothetical gas. It is evident, furthermore, that the difference in nomenclature introduced by Praxagoras does not correspond with the distinction between veins and arteries, as now understood. In his doctrine the veins, as containing blood, still bore their old name of φλέβες, or bloodvessels, while the latter assumed a new character, and were designated accordingly as arteries, or air-tubes. This forms a remarkable episode in the history of medicine; in which a serious error, apparently grounded on anatomical evidence, appears as a necessary phase in the development of physiological knowledge. At all events, it remained for several centuries the accepted doctrine, and passed the inspection of more than one investigator, no less able and distinguished than its author.

But what became of the *trachea* after its name, ἀρτηρία, had been applied to another system of vessels? The term was modified to correspond with the structural peculiarities of the organ. The arteries proper are of smooth and uniform texture; but the trachea is rough and uneven, being formed of cartilaginous rings with membranous spaces between them; and it was called, therefore, the ἀρτηρία τραχεῖα, or the "rough air-tube." This is the first appearance of our modern name for the organ. We have now dropped half its title, and call it simply the "trachea." But the French retain the double appellation, and with them it is still known as the "trachée-artère."

CHAPTER III.

THE SCHOOL OF ALEXANDRIA.

THE school of Alexandria was in some respects the most remarkable product of Greek civilization. Created under the auspices of a successful military commander, it survived a change of masters at the Roman conquest, and a change of religion after the Christian era. Situated in Egypt, it drew teachers and students from every country bordering on the Mediterranean, and exercised an influence in science, literature, and philosophy, over the whole civilized world. It is of especial interest in connection with the history of medicine, because some of its most important achievements, for the first two hundred years of its existence, were in that department; and even so late as two or three centuries after Christ,* it was still the resort of those who wished to enjoy the best opportunities for medical instruction.

The city of Alexandria owed its origin to the political and military plans of the conqueror whose name it bears. When Alexander the Great had pushed his dominions to the east and south of the Mediterranean, he looked for a spot which should be capable of sustaining a great capital, and of serving as the centre of his extended empire. For this purpose he selected a site on the northern shore of Egypt, where a small

* Ammianus Marcellinus, Res gestæ, lib. xxii., cap. xvi.

village already existed, and which seemed to possess the requisite advantages. It commanded the main entrance to the inland navigation of the delta and valley of the Nile; and from its position on the Mediterranean it offered a central point of communication for travel and commerce between the north, the east, and the south.

But Alexander died about three hundred and twenty years before Christ, not long after the foundation of the city; and his favorite general, Ptolemy, who was already in command of the country as a province, became its permanent ruler, under the title of Ptolemy I., king of Egypt. He proved fully equal to the task of government; and under the impulse of his energy and foresight Alexandria became a large and prosperous city. It had two harbors protected by a long island running parallel with the shore, and joined to the mainland by a stone causeway or mole, three-quarters of a mile in length. The modern town is said to be built mostly on the ruins of this mole and the débris accumulated round it. The city extended for four miles along the shore, which was lined with piers and dockyards, busy with the commerce of the Mediterranean; and in the last century before Christ it had over half a million of inhabitants, and an annual revenue equivalent to more than $5,000,000,* from port dues alone. It was the second city in importance of the known world, and the first in commercial enterprise and activity.

But beside its advance in material prosperity, Alexandria also became a centre of learning. Ptolemy,

* Smith's Dictionary of Greek and Roman Geography, Boston, 1854, vol. i., p. 100.

who was a man of some education, wished to make his capital a resort for scholars, and a place where knowledge as well as wealth could be imparted and acquired. For this purpose he founded and maintained, from the treasury of his kingdom, the Musæum of Alexandria—an institution corresponding to our modern idea of a university. It was an establishment for the general teaching and cultivation of science, literature, and art. It was provided with buildings containing a library, apartments for professors, a theatre for public meetings, lectures, and addresses, and in course of time with botanical and zoological gardens for the practical study of natural history. One of its most important and original features was its library; a department which was established and fostered with such zeal and liberality of expenditure, as to be an object of active but unsuccessful rivalry among the neighboring States. It is not quite certain by whom its formation was suggested; but it is generally admitted that nothing of the kind had been in existence before. There were many valuable manuscripts in the hands of private owners who, no doubt, spent much time and labor in completing or enlarging their collections. But the idea of a great public library, open to all comers, for the general increase and dissemination of knowledge, was first conceived and carried into execution at Alexandria. Whenever manuscripts of recognized merit were known to be for sale, they were purchased and deposited in the musæum, until its possessions amounted to about 500,000 volumes. The office of director of the library was an important and responsible post, both for the preservation and management of the books already acquired, and for the selection and purchase of others. These abundant resources, no doubt, offered to all interested in literary or scientific matters a great attraction, as well as an invaluable aid for the prosecution of their studies; and in the opinion of some writers* such an establishment must have exerted, in ancient times, as great an influence as the invention of printing in modern civilization.

The school of Alexandria had a success commensurate with its opportunities, at least during the earlier periods of its existence and in the natural and mathematical sciences. The list of its teachers and pupils includes Euclid in geometry, Strabo and Eratosthenes in geography, Archimedes in physics, and Hipparchus and Ptolemæus in astronomy; representative men, whose names are indispensable landmarks in the history of human knowledge. In medicine it became so pre-eminent as to take the lead of all contemporary schools.† It was for several centuries the source from which all medical discoveries emanated, and a common centre where all medical theories and doctrines were promulgated and discussed.

Among the medical celebrities of the school of Alexandria the two, whose names stand out in deserved prominence from the rest, are the anatomists, Herophilus and Erasistratus. They lived within the reigns of the first two Ptolemies, and were probably contemporary or nearly so with each other. Herophilus seems to have been earliest on the ground, and probably acted as teacher of anatomy almost from the foundation of the school; while Erasistratus came to Alexandria later

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* Renouard, Histoire de la Médecine, Paris, 1846, tom. i., p. 261.

† Matter, Essai Historique sur l'Ecole d'Alexandrie, Paris, 1820, tom. i., p. 4; tom. ii., p. 79.

in life, giving up the study and practice of other departments to devote himself wholly to anatomy. But the two were so closely associated in time, by the nature of their discoveries, and by the influence which they exerted, that their names appear together as belonging to a single epoch.

The services which they rendered to anatomy did not consist alone in the discovery of details, or the more accurate description of bodily structures. They inaugurated a new method, which placed anatomy on a surer and more advantageous footing than it had ever before occupied. It was in their time, and at the Alexandrian school, that the dissection of the human body was first legalized by public enactment. Ptolemy I. and Ptolemy II. authorized these anatomists to use for dissection the bodies of condemned criminals, assigned to them for that purpose from the public prisons. This enlightened policy certainly reflects credit on the monarchs who adopted it; but it also shows the character and influence of the anatomists who could advise and carry out such an innovation. Human anatomy, it is true, was by no means a new science. The works of earlier authors contain descriptions and allusions which can hardly admit a reasonable doubt that it had already been studied by means of dissection. But this method had not been employed, so far as we know, in any systematic way, nor with any other sanction than the individual judgment and responsibility of the dissector. At Alexandria it was made a recognized means of instruction; and it is easy to see how greatly this must have contributed to the progress of anatomical science. Herophilus and Erasistratus were not the first anatomists; but they were the first who, under legal provision, pursued the study of practical anatomy, for their own improvement and the benefit of their pupils, in a public institution.

The original works of the Alexandrian anatomists are no longer in existence, and our knowledge of them is obtained through Plutarch, Celsus, Rufus Ephesius, and especially through Galen, who quotes them with great frequency and on a variety of topics. From these sources we learn that they enriched anatomical science with many important facts, and in not a few instances gave to organs or structures the names which are retained at the present day. The *tricuspid* valves of the heart,* and the *parenchyma* of the internal organs† received their designations from Erasistratus or his disciples; the *duodenum*,‡ and the *calamus scriptorius*,§ from Herophilus; the term *choroid*|| was first applied by him to the vascular lining of the ventricles of the brain (tela choroidea), and also probably to that of the eyeball¶ (tunica choroidea); and the occipital confluence of the sinuses of the dura mater is called the *torcular Herophili*, because he compared it to the receptacle of a wine-press.**

Our knowledge of the anatomy and physiology of the *nervous system* dates from Herophilus and Erasistratus. Before their time the word νεῦρον (nerve) signi-

* Galen, Opera Omnia, vol. v., p. 548.

† Galen, Opera Omnia, vol. xv., p. 8.

‡ Galen, Opera Omnia, vol. ii., p. 780.

§ Galen, Opera Omnia, vol. ii., p. 731.

|| Rufus Ephesius, De Appellationibus, lib. i., cap. xxii.

¶ Rufus Ephesius, De Appellationibus, lib. i., cap. xxiii.

** Galen, Opera Omnia, vol. iii., p. 708.

fied simply a *cord*, and would be correctly translated "tendon," "sinew," or "ligament;" for the nerves proper were confounded with the tendinous structures, and were supposed to act in the production of movement only by their physical properties. Herophilus first made a physiological distinction between these different kinds of cords; some of them, the nerves proper, which are the ministers of volition, taking their origin from the brain and spinal cord; while others have both their origin and insertion in the bones (ligaments), or pass from muscle to muscle (fasciæ), or serve to connect the articulations (tendons or sinews).*

He, as well as Erasistratus,† furthermore distinguished two classes of nerves, namely, the nerves of sense, *αἰσθητικοί*, and those of motion, *κινητικοί*; and it is a striking instance of the progress made during their time in this department, that Erasistratus, who at first believed the nerves of sense to originate from the dura mater, afterward described their true origin from the brain. The reasons for this mistake, and the mode in which it was corrected, are explained by Galen;‡ and they show how naturally the older anatomists were led to confound nerves and tendons together. The nerves of the body and limbs have, in fact, much of the physical quality of tendons, owing to their neurilemma or external fibrous envelope, which is dense and resisting. The internal or medullary portions must have required, for their first demonstration, no little skill and expe-

* Rufus Ephesius, De Appellationibus, lib. ii., cap. xvii.

† Galen, Opera Omnia, vol. iii., p. 813; and Rufus Ephesius, De Appellationibus, lib. ii., cap. xvii.

‡ Galen, Opera Omnia, vol. v., p. 602.

rience in the dissector. According to Galen, the attention of Erasistratus being taken up for a time with the fibrous investment of the nerve, which really proceeds from the dura mater, he supposed its whole structure to be derived from this membrane; and in most of his works the nerves are described as originating from the membranous envelope of the brain. But in the latter part of his life, when he devoted more time to technical investigation, and dissected with greater accuracy, he recognized the medullary part of the nerve as an outgrowth from the cerebral substance.

The knowledge of the structure and properties of the brain and spinal cord was also greatly advanced by the Alexandrian anatomists. Both these organs had been misunderstood by earlier writers. Largely composed of a white, soft, apparently homogeneous and non-vascular substance, they had been regarded as inactive deposits of lardaceous material, somewhat analogous to the marrow of the bones.* The name, "spinal marrow," so long retained afterward, indicates the unimportant character at first attributed to this part of the nervous system. Herophilus, on the other hand, made the brain an organ of commanding influence in the animal economy. According to him, it was the seat of conscious individuality,† the centre of the perceptive faculties, and the source of voluntary action. With its nerves of sense and motion it thus became, in his doctrine, the essential instrument for the manifestations of *animal* life; that is, the immediate functions of the so-called "anima," the immaterial principle of independent existence. He probably

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* Aristotle, Opera Omnia, vol. iii., p. 237.

† Galen, Opera Omnia, vol. xix., p. 315.

treated of its anatomy very fully, as he knew all its ventricles, attributing to the fourth, or that embraced by the cerebellum, the most important part in the transmission of stimulus to the spinal cord;* and he recognized, on the floor of this ventricle, the well-known configuration of the medulla oblongata which he designated by an appropriate name.† Erasistratus described faithfully the convoluted structure of the cerebrum and cerebellum, and asserted that these convolutions were more abundant in man than in the lower animals, in proportion to the superiority of his intelligence.‡ There appears ample reason to justify the opinion of Le Clerc,§ that "Herophilus and Erasistratus discovered the real uses of the brain and nerves."

In regard to the *vascular system* the doctrines of the Alexandrian school were a continuation of those of Praxagoras. The veins and the arteries were divided in function as before; the veins serving for the reception and distribution of blood, the arteries for the conveyance of air. The truth of this doctrine was never doubted throughout the long period of four or five centuries, which was marked in this school at first by so much original investigation, and afterward by an equal activity in theoretical discussion. It formed the basis of numerous researches on the character and significance of the pulse, of nearly all explanations of febrile and inflammatory affections, and of the mode of action of most of the organic functions. It was the

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* Galen, Opera Omnia, vol. iii., p. 667.

† Calamus scriptorius.

‡ Galen, Opera Omnia, vol. iii., p. 673; and vol. v., p. 603.

§ Histoire de la Médecine, Paris, 1729, p. 299.

main feature in the vascular physiology of this period, to which all its principal phenomena were referable and subservient.

It is, therefore, important to understand, if possible, the nature of the aëriform fluid, the so-called *pneuma*,* which the arteries were supposed to contain. But it is very difficult to gain an adequate comprehension of this term, as used by the ancient writers. There is nowhere to be found an exact definition or even a description of it; probably for the reason that it was then universally understood in a general way, perhaps without being susceptible of delineation in concise language. We are obliged to depend for our conception of its significance mainly on the context; and even this varies somewhat in different instances. Usually it is plain that the pneuma is derived from the external air, is introduced into the lungs by inspiration, and thence transferred to the heart and arteries. But it is not the atmospheric air in bulk which gains access to these vessels; it is something either extracted or produced from it, which only assumes the name and qualities of the "pneuma" after its entrance into the system. An over-zealous interpretation of the ancient writers might even suggest the idea that they knew of the existence and properties of oxygen as an element in the atmosphere, and the part which it plays in respiration. On the other hand, they not unfrequently speak of the arteries as containing "air;" and even the name of these vessels, which was that originally applied to the trachea, shows that they were in some sense regarded as "air-tubes."

* Πνεῦμα, from πνέω, to breathe. Its Latin equivalent is *spiritus*, breath, contracted in English into *spirits*.

But this discrepancy is easily explained. Among the ancients the term "air" did not mean the atmosphere, but simply an aëriform fluid; that is, any substance having a gaseous or vaporous constitution. Furthermore, they did not understand the atmosphere in its modern sense, as a definite mixture of specific gases, of known qualities and in known proportions. It was for them only an invisible aëriform envelope, which might contain a variety of substances undistinguishable from each other, except by the effects which they were capable of producing. The pneuma itself they never attempted to isolate or examine by means like those of modern chemistry, and consequently they could not describe it in terms like those now employed. But it is evident that they fully believed both in its existence and its importance; and we can perhaps make an approach to understanding their views in the following way:

The most palpable fact in physiology is the vivifying influence of the atmospheric air. Its access is indispensable to the maintenance of life; and in all the higher animals the process of respiration must go on without serious interruption, in order to keep up the phenomena of consciousness and vitality. This is a truth which must have been known from time immemorial, and does not require for its demonstration any elaborate scientific research. The act of respiration is instinctively regarded as the sign of vitality; and the "breath of life" is an expression which probably has its equivalent in every language. Whatever may be the constitution of the atmospheric air, it is plain that it supplies to the living body something essential to its existence. This something is not a solid nor a liquid. It does not add to the mass of the bones or the flesh or the blood. But it is of great power, for it quickens into activity the bodily organs, and stimulates them to the performance of their functions. It is an invisible, intangible vapor; and as it is taken in by respiration, it is called "pneuma," or the essential element of the breath (20). It represents the impulsive force of the living organism; while the solids and the fluids are the instruments with which it works, or the materials used for nutrition.

The doctrine of the pneuma received, early in the history of the Alexandrian school, a further amplification. Erasistratus recognized two kinds of pneuma, with different qualities and modes of action. One was that immediately produced from the inspired air, namely, the πνεῦμα ζωτικὸν, *spiritus vitalis*, or "vital spirits." It was this which filled the left cavities of the heart, and the arteries throughout the body.* As its name implied, it gave the immediate stimulus to the functions of organic life. It was the cause of the cardiac and arterial pulsations, the source of internal heat, and the direct agent in the production and maintenance of digestion, nutrition, and assimilation. The other was the πνεῦμα ψυχικὸν, *spiritus animalis*, or "animal spirits." It was elaborated from the former in the brain,† where it occupied the cavity of the ventricles, and was thence sent through the nerves to the organs of sensibility and volition. It was consequently the direct agent of the ψυχή, or *anima*,‡ the moving force of

* Galen, Opera Omnia, vol. v., p. 185; vol. viii., p. 714.

† Galen, Opera Omnia, vol. v., p. 281.

‡ Usually translated "soul."

individual consciousness and life, with its powers of perception and spontaneous action.

The reasons for introducing this additional element in the doctrine of the physiological forces were, no doubt, the discoveries of Herophilus and Erasistratus in the nervous system. These discoveries showed that there was something to be accounted for which had not yet received explanation. The brain, never before regarded as of any special physiological value, was now the centre of consciousness and volition; and the nerves, no longer simple tendinous cords, were the pathways of an invisible force between the brain and distant parts. Thus the functions of the living body were divided into two classes, confided to two different sets of organs. In the vascular system and the abdominal viscera were the processes of organic life, maintained and directed by the *spiritus vitalis*, the immediate product of respiration. In the nervous system were the acts of animal life, bringing the individual into conscious relation with the outer world, through the special agency of the *spiritus animalis*, or nerve force, generated in the brain. This subtle emanation, impelled through the nerves of sense and motion,* gave rise to the perceptions of sight, smell, hearing, taste, and touch, or conveyed the stimulus for voluntary movement ;† and by its influx into the muscles it caused their contraction, by expanding them laterally and shortening their longitudinal dimensions (21).

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* These nerves were called *πόροι* and *ὁδοὶ*, "passage-ways" or "paths." Galen, Opera Omnia, vol. iii., p. 813; vol. vii., p. 89; vol. xix., p. 30.

† Galen, Opera Omnia, vol. v., pp. 614, 616; vol. viii., p. 233; vol. xix., p. 313.

This doctrine was evidently well suited to the needs of physiological science at the time, for it was not only immediately accepted, but remained firmly established long afterward. The terms, "vital spirits" and "animal spirits," held their place in medical literature throughout the remainder of the ancient period, during the whole of the middle ages, and even for a considerable part of the modern epoch. Their reality began to be doubted in the seventeenth century,* but their probable existence and modes of action were still discussed by Haller† in the eighteenth; and in Bonnet's *Theory of the Inclusion of Germs*,‡ the "nervous fluid," or animal spirits, plays an important part. Since then the effects formerly attributed to "spirits" have been referred to the so-called property of *irritability* resident in the tissues and nerves.

Another change of nomenclature, adopted about the same time in the school of Alexandria, was in regard to the two great vessels connecting the lungs and the heart. According to the views then in vogue, the vascular apparatus in general consisted of the veins or bloodvessels on one side, and the arteries or air-tubes on the other, connected respectively with the right and left cavities of the heart. On the right side were the great veins supplying blood to the body at large, and a special vein (now the pulmonary artery) conveying nutriment to the lungs. On the left side was a special artery (now the pulmonary vein) coming from the lungs

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* On the *Nullitie of Spirits*, in the Discourse of James De Back, London, 1653.

† Elementa Physiologiæ, Lausannæ, 1757, tom. iii., p. 332; tom. iv., pp. 386, 403.

‡ Bonnet, Œuvres complètes, Neuchatel, 1781, tom. x., pp. 7, 8, 9.

to the heart, and bringing into the left ventricle the pneuma, which it had received from the bronchial tubes, and which was then disseminated by the aorta and its branches throughout the body. A vein, accordingly, was called a vein because it contained blood; and an artery was an artery because it contained pneuma or air. But in the case of the lungs these vessels were peculiar in structure. The vein, or bloodvessel, leading from the right ventricle to the lung, had thick and fibrous walls, like those of an artery; and it was named by Herophilus the φλέψ ἀρτηριώδης, *vena arterialis.* On the other hand, the vessel coming from the lung to the left ventricle, though belonging to the arterial system and performing the office of an artery, had thin and flexible walls, like a vein; it was, therefore, called the ἀρτηρία φλεβώδης, *arteria venalis* (22).

These vessels continued to be known as the *vena arterialis* and the *arteria venalis* so late as the seventeenth century. Harvey usually calls them the *vena arteriosa* and the *arteria venosa*, though he sometimes employs the older form. In the latter part of the century there is evidence of a change of appellation, the *vena arteriosa* being called by some the "pulmonary artery," and the *arteria venosa* the "pulmonary vein;"* and in the works of Haller† the modern designation only is used. By that time the doctrine of the circulation was so fully established that the terms "artery" and "vein" signified mainly the direction of the blood-current to or from the organ in question; the vessel bringing the blood from the heart to the organ being

* Bartholinus, Anatome, ad circulationem Harvejanam et vasa lymphatica quartum renovata, Lugduni Batavorum, 1673, p. 404.

† Elementa Physiologiæ, Lausannæ, 1757.

an artery, and that returning the blood from the organ to the heart being a vein. Under this nomenclature, the vessels of the same name are alike in structure as well as in function.

A most important contribution to the anatomy and physiology of the circulatory apparatus was that of the *cardiac and arterial valves.* It is plain, from references by Galen, that Erasistratus accurately described all these valves and their action. According to him, they provide the mechanism by which the heart alternately takes in and expels blood on the right side and pneuma on the left. They are designated as "membranes," attached to the orifices of the incoming and outgoing vessels, and so arranged that they open in one direction and close in the other. Those at the entrance of the vena cava, in the right ventricle, have the form of triple points, and are therefore called "tricuspid;" those at the entrance of the pulmonary vein, in the left ventricle (mitral valves), are also pointed, but are only two in number. Both these sets of valves open inwardly, allowing an influx into the heart at its diastole, but close outwardly, preventing an escape at its systole. Each of the outgoing orifices (pulmonary artery and aorta) has three valves, of semilunar form, which open from the heart toward the vessels, but close in a backward direction, and prevent regurgitation (23).

Notwithstanding this complete knowledge of the cardiac valves, there was no idea of a circulation of the fluids, or even of a continuous current. The diastole of the heart, in the physiology of the period, is an active expansion, drawing into the right ventricle, as if by suction, a little blood to be used for the nourishment of the lung, and into the left ventricle a little pneuma or "spirit," to supply the arteries. Both veins and arteries, as in the time of Aristotle, are still called "receptacles," and provide for the diffusion of their contents through the body, only by their form of tubular ramification.

Lastly, an equally remarkable feature in the teaching of the Alexandrian school was that of the *anastomosis* between the veins and the arteries. The evidence of this doctrine is unmistakable; and it even formed a basis for important pathological theories. It was not an anastomosis by continuous channels, nor did it provide for the constant passage of fluids from one set of vessels to the other. It was rather a communication which might be open or shut according to circumstances, and when open was usually a cause of injury, rather than benefit, to the system at large. It is described by Galen, in his account of the production of fevers and inflammations according to Erasistratus.

"In considering this subject," he says, "I think it best to begin with the doctrines of Erasistratus, which I will present as briefly as possible. According to him, the artery is a vessel containing pneuma, the vein one containing blood. The vessels, as they are distributed through the body, continually divide, diminishing in size and increasing in number, so that there is no place without a vascular extremity. But these terminal ramifications are so small that the blood is retained within them by the coaptation of their walls. Consequently, although the mouths of the vein and the artery lie side by side, the blood nevertheless remains in its own vessels, and nowhere penetrates into those of the pneuma. So far, the system is in its normal condition. But when, from any disturbing cause, the blood is forced over from the veins into the arteries, a morbid action results. There may be several such causes, one of the most important of which is a *plethora of the blood.* By this, the blood-vessel is distended, and its extremities, previously closed, forced open; when the blood is transfused into the arteries, coming in conflict with the pneuma from the heart, and interfering with its motion. If this take place near the source of the pneuma, toward the heart, it produces fever; but if the blood be driven forward by the pneuma and impacted in the terminal arteries, it causes inflammation. It is in this way that inflammation arises from plethora. It may also result from *wounds;* but in that case the transfusion is due to the natural movement for filling a vacuum. For as the pneuma escapes from the divided arteries it tends to leave behind it a vacancy; and the blood consequently follows, through the vascular anastomoses, to occupy its place."*

These alleged communications between the veins and the arteries were, therefore, to all appearance hypothetical. It was not claimed that they were demonstrable to the senses; and they were hardly supposed to exist, as practicable openings, in the usual state of the vessels. But they seem to have been assumed, as affording an explanation of the general disturbance in febrile affections, and of the congestion and throbbing in local inflammations. In the physiological operation of the vascular system they had no part; for under all normal conditions the blood was contained only in

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* Galen, Opera Omnia, vol. xi., p. 152.

the venous portion of this system, and the pneuma or "spirits" in its arterial portion. In this way the body was supplied, on the one hand, through the veins, with the liquid materials of nutrition and growth; on the other, through the arteries, with the exciting and controlling forces of physiological action.

CHAPTER IV.

GALEN.

In the second century of the Christian era the error which had so long obscured the doctrine of the arteries came to an end. For five hundred years these vessels had been regarded as air-tubes; and this mistaken belief, lying at the foundation of vascular physiology, had interposed an effectual barrier to any further advance in the knowledge of the circulation. It was dissipated at last by the genius and originality of Galen; and the arterial system took its place as a system of vessels for the reception and conveyance of blood. From that time the distinction between veins and arteries became a real one. Both were bloodvessels; but in one set the blood which they contained was venous, in the other it was arterial.

In every respect the name of Galen stands preëminent in the history of medicine. He is the central figure, representing at once the culmination of medical science and art in the old world, and their preservation for further development under a new civilization. He lived at a time when the Roman empire had reached its highest point of prosperity, without yet showing the signs of its deterioration. A Greek by birth and education, he practiced his profession at Rome, where he was the medical adviser of the imperial family and the most eminent among his colleagues in public estimation. He was, therefore, for some years the leading physician in the first city of the world. On the other hand, he had no successor who could be called a rival. His age was followed by the disintegration of the empire and the disappearance of learning in the middle ages; and for a long time afterward his works were the principal depository of medical knowledge, to which other writers resorted for their supply of materials. In the thirteenth century, the recognized text-books for instruction, in the school of Salernum, were the authentic works of Hippocrates and Galen.* So late as the sixteenth century, the lectures of the professors, in the Faculty of Medicine at Paris, consisted mainly of commentaries on the same authors;† and at that time the authority of Galen in anatomy was still so great, that it was considered presumptuous to question the accuracy of his descriptions, even from the evidence of actual dissection.‡

This extraordinary supremacy, which lasted for over fourteen centuries, was due, partly but not entirely, to the ignorance of the middle ages, which made it impossible for them to compete with the best writers of antiquity. As a matter of fact, Galen was the medical teacher of Europe during the period of its intellectual pupilage; but his reputation had been established beforehand, from the real superiority of his talent, the extent of his knowledge, and the value of his discoveries and investigations.

Fortunately his writings have come down to us with

* Huillard-Bréholles, Historia diplomatica Frederici Secundi, Paris, 1854, tom. iv., p. 236.

† Corlieu, L'ancienne Faculté de Médecine, Paris, 1877, pp. 125, 134.

‡ Daremberg, Histoire des Sciences médicales, Paris, 1870, tom. i., p. 211.

but little loss or mutilation. Nearly the whole of his more important works are now preserved, in various European libraries, in the form of manuscripts in the original text (24), beside Latin versions and commentaries by mediæval writers; and, with one or two exceptions, they are all contained in an Aldine edition, printed in 1525. These works are extensive and varied. They include systematic treatises on anatomy, physiology, hygiene, the action of drugs, diagnosis and prognosis, pathology and therapeutics; beside special works, or monographs, on the pulse, the vocal organs, dyspnœa, epilepsy, phlebotomy, antidotes, mental affections, and malingering. They present an epitome of medical doctrine and practice in the time of their author, enriched by his own contributions and his commentaries on previous writers.

The most marked peculiarity of medicine in Galen's time was that of the so-called "sects," into which the profession was divided. These sects had grown up during the later periods of the Alexandrian school, owing to its activity in theoretical discussion and the wide influence of its successful teachers. They were mainly four in number: first, the "dogmatists," who contended for *rationalism* in medicine, that is, an intelligent study of the pathology of disease, and a reasonable adaptation of treatment to morbid conditions; secondly, the "empiricists," who believed in *experience* as the only guide to successful practice, rejecting the consideration of morbid causes as too obscure; thirdly, the "methodists," who admitted in their pathology only the simplest and most intelligible conditions, such as constriction and relaxation, with increased or diminished freedom of movement in the molecules of the body; and lastly the "pneumatists," who referred disease to the operation of unseen influences (*pneumata*), derived from without. It appears that these systems all had their foundation of truth; and each was no doubt adopted, in the first instance, as a protest against the extravagances of the rest. But in course of time they had become so amplified and elaborated by the zeal of their partisans, that each claimed to represent the whole of medical science and art; and in order to meet these extended requirements, they had been so overloaded with verbal distinctions and niceties of definition as to be often practically unintelligible. Nearly every physician belonged to one or the other of these sects. The adherents of each were in opposition to all the rest; and they were so exclusively attached to particular doctrines that, as Galen says, the "followers of Moses and of Christ would give up their religion, rather than these doctors the tenets of their sect."*

Galen was thoroughly acquainted with these systems, and presents them to the reader in a very impartial way; but he did not profess adhesion to either, and he considered it a "servitude" to embrace exclusively the doctrines of any single belief.† He had great admiration for Hippocrates, as the teacher whose precepts were sounder and more valuable than those of any other. But this was not a servile and barren admiration; for he believed that the highest tribute which could be paid to such a master would be the adoption of his method for adding to knowledge by continued research.

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* Galen, Opera Omnia, vol. viii., p. 657; vol. xi., p. 432.

† Galen, Opera Omnia, vol. xix., p. 13.

"There are many physicians," he says, "like the athletes who would like to win prizes in the Olympic games, but will not take the pains necessary to gain them. For they are loud in their praises of Hippocrates, and give him the highest rank as a physician, yet never think of imitating him themselves." . . . . . "It is certainly no small advantage that we enjoy, to live at the present day with the arts already brought to such a state of perfection; and it would seem not too much for us, after learning in a short time what Hippocrates discovered by many years of labor, to employ the rest of our lives in investigating what still remains unknown."*

Galen had no taste for disputing about words or names, which he thought of but little consequence, except for what they signified; and he criticised the sectarian writers of the day for their verbose technicalities, many of which, he said, were as hard to comprehend as the "riddles of the Sphinx."† One of these authors, Archigenes, had written a book of some celebrity on the *pulse*, in which he multiplied the subtleties of definition and classification, and increased their obscurity by his unusual and peculiar phraseology. He assigned to the pulse eight different qualities, which he designated by a new term, representing its size, force, velocity, frequency, fulness, regularity, uniformity, and rhythm, beside divisions and subdivisions of the two extremes and the natural mean, the long, the large, and the high pulse, and so on, to an excessive degree.

Galen objected to this that there was too much fancy

* Galen, Opera Omnia, vol. i., pp. 53, 57.

† Galen, Opera Omnia, vol. xviii., part 2d, p. 300.

in it, and too little reality. "There is a mistake," he says, "that Archigenes makes at the outset, in enumerating the qualities of the pulse. For he does not attempt to show why they should be reckoned as so many, but simply makes the assertion, and says that there are eight qualities belonging to the pulse, called by the purists διηχημέναι. As for me, however, I cannot even guess the meaning of this term διηχημέναι, and do not know of its being used by any of the Greek writers. Consequently I have no idea what Archigenes means by it, especially as he has not written a book to explain his own idiom, as Chrysippus did about the words in his *Dialectics*. That would really have been the way to make himself understood. Without the context, indeed, you might suppose that he used the word in its regular and customary sense. But he is careful to prevent this, for the qualities of the pulse, he says, are so called, not by everybody, but only by the 'purists;' and we do not even know who these purists are."*

The faults of excessive sectarianism are illustrated by Galen from the case of two patients bitten by a mad dog; and the passage shows how well the symptoms and treatment of this malady were understood in ancient times. Galen is pointing out the error of the empiricists in repudiating all consideration of the hidden causes of disease, and depending only on what is evident to the senses. "But, perhaps, I can show," he says, "that you overlook something in this exclusive attention to the phenomena. Suppose that two men have been bitten by a mad dog, and that each has gone

* Galen, Opera Omnia, vol. viii., p. 578.

to his physician for treatment. The injury in either case is a slight one, and does not quite go through the skin. One of the physicians is solicitous only for the cure of the wound, and in a few days has the part entirely healed. The other, understanding that the dog was rabid, does exactly the opposite, enlarging the wound by strong and caustic applications, and giving the patient in the meantime anti-rabific medicines. But what is the result in these two cases? The patient who was treated with remedies comes out safe and sound; the other, who thought there was nothing the matter with him, is suddenly taken with hydrophobia, and dies in convulsions."*

Galen was devotedly fond of anatomy, and insisted upon it as an indispensable basis for rational medicine. He was much impressed with the manner in which the animal structures are adapted to their functions; declaring that in his view there "is nothing in the body useless or inactive, all parts being arranged to perform their offices together, and endowed by the Creator with specific powers."†

Among his anatomical descriptions there are none more striking than that of the heart and bloodvessels in the fœtus, and their changes after birth. The Alexandrian anatomists had already described the cardiac and arterial valves as they exist in the adult. Galen's knowledge went farther. He was not only acquainted with the foramen ovale and the ductus arteriosus, as peculiarities of the fœtus, but his account of the manner in which these communications become obliterated

* Galen, Opera Omnia, vol. i., p. 88.

† Galen, Opera Omnia, vol. iii., p. 268.

after birth, one by the agglutination of its membranous valve, the other by a process of atrophy and shrinkage, is remarkable for its faithful and graphic description. "In this matter," he says, "we have reason to admire the provisions of nature. For so long as the lung has only to be nourished and grow, it is supplied simply with blood; but, when it is ready to take on an active motion, its tissue becomes lighter and capable of expansion and compression by the movements of the chest. On that account the vena cava, in the fœtus, communicates by an opening* with the arteria venalis (pulmonary vein). As this latter vessel thus performs for the lung the office of a vein (that is, supplies it with blood for its nourishment), its companion (the pulmonary artery) must needs at this time serve the purpose of an artery, and it is consequently made to communicate with the aorta. As these two vessels (pulmonary artery and aorta) are situated a little distance apart, their communication is effected by means of a third smaller one (ductus arteriosus), which forms a junction with each. In the case of the other two (vena cava and pulmonary vein), which lie in contact with each other, there is a kind of orifice or fenestra (foramen ovale), common to both. At this orifice there is attached a membrane, like a lid or cover, opening toward the pulmonary vessel, so that it will yield to the influx of blood from the vena cava, but will prevent its regurgitation into that vessel."

"So far, no doubt, we have much to admire in these contrivances of nature; but what surpasses them all is

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* This opening is the foramen ovale, leading from the right auricle to the left. Like other ancient writers, Galen regarded the auricular cavities only as expansions of the vena cava and the pulmonary vein.

the way in which the foramen not long afterward becomes occluded. For soon after birth, either within a day or two, or, in some animals, after four or five days or a little longer, you will find the membrane at the foramen coalescing, but not yet fully adherent. Looking at the same place in the adult animal, you would say there had never been a time when it was open; and, on the other hand, in a fœtus, before or immediately after birth, when this membrane is attached, so to speak, only by its root, the rest of it hanging free in the vascular cavity, you would hardly believe in its ever becoming agglutinated. In like manner the connecting vessel (ductus arteriosus) between the aorta and the vena arterialis, while all other parts of the body increase in size, not only stops growing but actually diminishes, becoming after a time completely shrivelled and solidified."*

Galen's demonstration of the function of the arteries as bloodvessels is mainly given in his special treatise entitled, "*Whether the arteries naturally contain blood.*"† The significance of this designation is apparent when we remember that, according to the accepted doctrine which had come down from Erasistratus, the arteries, though normally containing only spirits, might sometimes become filled with blood from the veins; and that this unnatural transfusion was especially liable to occur when an artery was wounded. Under these circumstances the aëriform spirits were first discharged from the wounded vessel; the vacuum being supplied by a transudation of blood, which filled the artery and appeared at the wound (25). In this way

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* Galen, Opera Omnia, vol. iv., p. 243.

† Galen, Opera Omnia, vol. iv., p. 703.

the doctrine accounted for the discharge of blood from an open artery, referring it to the unnatural relations established by the wound. Galen's demonstration was intended to show that the arteries contain blood in their normal condition; and that, when it escapes from their wounded orifices, it does so because it was there beforehand.

But this demonstration, apparently so simple now, involved at that time many other considerations. It was believed that two sets of vessels, so unlike in structure as arteries and veins, could not be intended to contain the same liquid. The idea of the vital spirits, disseminated throughout the body by the arterial system, had been accepted for centuries as a fundamental truth of physiology; and, moreover, the pulsating movement of the arteries, so different from the inactivity of the veins, was a distinctive feature, corresponding with their supposed function as the channels of vitality and force. This doctrine was so fixed in the minds of physiologists that they failed to appreciate the simple fact of hemorrhage from a wounded artery; and all their ingenuity was employed in finding an explanation for the entrance of the blood into a vessel where it naturally did not belong.

Galen treats the subject wholly from the opposite direction. He insists on the importance of the visible facts; and if there are hypothetical difficulties, he endeavors to reconcile them with the existing phenomena, instead of explaining the phenomena to suit the difficulties. He declares that, when an artery is wounded, it discharges blood at once, under all circumstances, wherever it is situated, and whether the wound be large or small. The direct inference from this would be that the vessel contained blood beforehand. It must be so, or else the blood is transfused into it from elsewhere. According to the doctrine of Erasistratus, the transfusion takes place at the anastomosing extremities of the arteries and veins. But this assumption presents an unavoidable contradiction. Before the blood can arrive at a wounded orifice all the vital spirits which the artery previously contained must first be discharged from the opening, and no such discharge is perceptible. Even if the vital spirits be so thin and ethereal as to escape detection by the senses, it must require some time for complete evacuation from a wound of moderate size. Yet the fact is, that if an artery be punctured "even by the finest needle," it is blood which is discharged "from the very first instant."*

To test this point, Galen performed a variety of experiments under different conditions. According to the received opinion, an artery which contains blood must have been previously emptied of its vital spirits. In that case, the arterial pulsation and muscular power would at once disappear in the parts below, because they were both dependent on the dissemination of vital spirits through the arteries. But the contrary is the fact; for the artery supplying an entire limb may be shown to be full of blood, though its trunk and branches are still pulsating, and the limb retains its muscular power.

"Any one who wishes can try the experiment, as we have often done, by opening the axillary artery. You can find it without difficulty, being guided by its pulsation even before removing the integument; for the

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* Galen, Opera Omnia, vol. iv., p. 708.

motion is perceptible for a considerable space in animals that are thin, and in those that are fat near the bend of the elbow. You will then open it by applying to it, as you choose, either the point of a writing style, a needle, a slender scalpel, or any similar instrument that will make a narrow cut; and you may thus prove on the spot all the facts before mentioned, and also that neither the arterial pulsation nor the action of the muscles is in any degree impaired" (26).

If these two important functions, therefore, go on undisturbed, notwithstanding that the artery is full of blood, what foundation is there for the claim that its condition is an unnatural one? Galen considers this point as of great importance; and he carries its demonstration still farther by applying to an artery two ligatures a little distance apart, and then opening the vessel between them.

"On many occasions, after uncovering some large artery convenient for the purpose (the most convenient are those of the shoulders or thighs), we have asked the adherents of Erasistratus whether even then, immediately after being exposed, the vessel did not appear to contain blood. They could not help admitting the fact, both because Erasistratus himself says that, in removing the integument, there is a discharge of blood from the artery; and, furthermore, because it was made evident to the senses; for, by securing the artery with a cord on two sides, and then opening it in the middle, we showed it to be full of blood" (27).

The Alexandrian physiologists were at a loss to understand how vitality and motion could be preserved, and the life-giving *pneuma* distributed throughout the body, if the arterial system were occupied by so gross a liquid as the blood. But Galen showed that their own hypothesis, when tested by experiment, presented a still greater difficulty. If a wounded artery, owing to the escape of its vital spirits, fills with blood from its anastomotic extremities, the whole of its trunk and branches, between these extremities and the wound, must first be emptied of spirits and then filled with blood. If it be the axillary artery, all the arteries of the arm, forearm, and hand must be in this condition before a drop of blood can exude from the punctured vessel. But, furthermore, the vital spirits must also be evacuated, in such an experiment, from the portion of the artery toward the heart, and even from the aorta and its main divisions; for the cavities of all these vessels are continuous, and there is nothing to prevent the escape of the thin and volatile spirits from either direction. Consequently before a wounded artery, even of moderate size, can bleed, the vital spirits must be evacuated from the whole arterial system. This, according to the doctrine of Erasistratus, would leave the animal without sense or motion; and we know that nothing of the kind happens. That it must be so, if the arteries are normally filled with spirits instead of blood, is shown by the fact that when you bleed an animal to death by opening an artery of considerable size, he loses blood, not only from the distal portion of the vessel, but from that toward the heart, and also from all the other arteries, the whole of the blood in the body being discharged from the wound (28). As the supposed transfusion takes place only at the terminal extremities of the vessels, this general emptying of the vascular system could not take place, unless the flow of blood from the wound were everywhere preceded by the evacuation of the vital spirits.*

It is evident that Galen in this, as in all his physiological works, bases his convictions mainly on the visible and palpable phenomena. He believes in direct experiment as the surest guide to truth; and, if his discourse often takes the form of dialectic argumentation, it is only for the purpose of convincing his opponents, and showing the futility of their objections. The dogma, that "nature could not have made two kinds of vessels, both intended to contain blood," does not trouble him. "You might as well say," he replies, "that the several stomachs of ruminating animals were not all intended as recipients of the food; but that one must be meant for solids, one for liquids, and one for spirits. They are all recipients of the same thing, but each nevertheless has its separate use. So it is with the arteries and veins."†

According to Galen, therefore, the arteries are blood-vessels. After giving in detail the proofs of his doctrine and refuting the objections against it, he touches upon the question why this truth has been so long obscured by the errors of the past. This is not the least interesting part of his treatise; and it places in strong relief the character of his mind and his scientific methods. "One may naturally ask," he says, "how it is that men of so much intelligence could have maintained an opinion so contrary to the truth, since they must have had some plausible reason for their belief? To which I reply that they have left on record in their writings the grounds on which their belief was founded;

* Galen, Opera Omnia, vol. iv., pp. 712-715.

† Galen, Opera Omnia, vol. iv., p. 722.

and these grounds, though plausible, are not really sufficient. In such matters a frequent source of error is the following. Everything which comes under the cognizance of human intelligence is comprehended either through the senses or by the reason; and as there are many things of a physical nature which escape the senses, so our reason often fails to master those of a different kind. A sincere lover of the truth, therefore, should never withhold his assent from things plainly evident on account of others which are obscure, nor accept those which are doubtful for the sake of what is really known." . . . . . "This is the mistake made by the disciples of Erasistratus. For their doctrine of the vacuity of the arteries was not based upon demonstration of the fact, but upon their uncertainty in regard to other matters. In this particular they were somewhat like those philosophers who denied that there could be any such thing as *motion* (29), because they were unable to solve their own problems in regard to it. In my opinion, it would have been better to concede the existence of motion in the first place as an evident fact, and study out the difficulties afterward at leisure. For the same reason I would admit that the arteries contain blood, from the fact that they discharge it at once whenever punctured by the finest needle. But why nature should have made two kinds of vessels to hold one kind of liquid; or how the spirits taken in with the breath can be transported throughout the body, if the arteries are filled with blood; or how, if the spirits be not so transported, the pulse and voluntary motion can be preserved;—all these are special difficulties, very proper to be considered and investigated by themselves, even if regarded as matters of uncertainty. But they ought not to outweigh the direct testimony of visible phenomena."*

In this way Galen accomplished a revolution in physiology, hardly surpassed in importance by any before or since. The older doctrine disappeared before the convincing force of his arguments and demonstrations; and his assertion that arteries, as well as veins, were the normal recipients of the blood, became the assured belief of the scientific world. But what were his ideas as to the physiological action of the heart and bloodvessels, and the functions of respiration, nutrition, and circulation? This is a question of much importance, because his views remained the accepted physiological doctrines for centuries afterward, and formed the basis for all subsequent changes and modifications.

The general features of Galen's physiology are to be found in his books on *The Functions of the Parts*, *The Causes of the Pulse*, *The Use of Respiration*, and *The Physiological Forces.* In this system, the liver was the central organ of nutrition and sanguification. From it all the veins took their origin; and in its glandular tissue the blood was prepared from the elements of the digested food. The veins of the portal system absorbed from the stomach and intestine the chyle (30), produced in digestion; and the chyle, conducted by the portal vein to the liver, was elaborated in this organ by a further process of coction or fermentation. This elaboration, Galen is careful to say, is not accomplished by the arteries, veins, or nerves of the liver, nor by the biliary ducts; but by the intervening substance of

* Galen, Opera Omnia, vol. iv., p. 720.

the organ (gland-tissue), which has the power of assimilation. Under its influence, the chyle approximated in its physical qualities to those of the liver substance, becoming thicker in consistency and ruddy in color, and was then ready to join the general mass of venous blood, for distribution throughout the body. From the convexity of the liver the vena cava extended in two opposite directions, upward and downward; supplying on the one hand the head and upper extremities, on the other the trunk and lower extremities. But the superior vena cava, communicating laterally with the right cavities of the heart, had a further extension beyond the right ventricle to the lungs. This branch, our pulmonary artery, was called the vena *arterialis,* because it resembled an artery in the thickness of its coats. But it was nevertheless a vein, continuous with the rest of the venous system, and containing, like the rest, venous blood.

In this way the blood in the venous system provided for the general nourishment of the tissues. On the other hand, the arteries were also full of blood, but of a different kind. The venous blood was dark, thick, and rich in the grosser elements of nutritive material. The arterial blood was thinner, warmer, bright-colored, and, above all, *spirituous;* that is, it contained an abundant supply of the vital spirits, which it distributed throughout the body. Its warmth it obtained from the heart, and especially from the left ventricle, in which the animal heat was generated; its vital spirits being also acquired in the same organ, but derived from the inspired air of the lungs. Thus, according to Galen, the arteries contained vital spirits, not in the form of a distinct gaseous body, but amalgamated with the other ingredients of the blood.*

The destination of these two kinds of blood corresponded with their different properties. Venous blood was for the nourishment of the thicker and denser parts, arterial blood for those of a lighter and more spongy nature; and, since every organ is supplied with both arteries and veins, it can absorb each kind of nutriment in due proportion for its own needs. In every case the process of nutrition was accomplished by transudation of the blood through the vascular walls.†

As the liver was the origin of the veins, so the heart was the origin of the arteries. From the left ventricle, the principal part of the organ, the great artery, or aorta, supplied, by its ascending and descending divisions, the head and upper extremities on the one hand, the trunk and lower extremities on the other; while a separate vessel was distributed to the lungs. This vessel (our pulmonary vein) was called the arteria *venalis*, because its walls were like those of a vein; but it was part of the arterial system, and contained arterial blood.

The vessels of this system were distinguished by the characteristic phenomenon of the *pulse*. As its name indicates, this was a shock, perceptible to the finger and caused by a dilatation of the artery in every direction.‡ Its importance was manifest from the fact that its continuance was a sure indication of vitality, and its cessation the sign of death. According to Galen, it

* Galen, Opera Omnia, vol. viii., p. 707.

† Galen, Opera Omnia, vol. iii., pp. 318, 449, 450.

‡ Galen, Opera Omnia, vol. viii., p. 455.

was due to a "pulsatile force" (31) resident in the walls of the artery, but derived by them from the heart, in which it also existed. This was a force of active expansion, dilating the artery and attracting the fluids into its cavity; while its subsequent contraction caused an expulsion of its contents in the same degree. Thus the diastole of the artery was an active, and its systole a passive movement, like those of the chest in inspiration and expiration;* and the two followed each other in turn, keeping up a continual interchange of the vascular contents. At its diastole the arterial system drew in spirituous blood from the heart, and at its systole it expelled the excrementitious impurities of the bodily waste. By this means it provided for the maintenance and supply of vital heat, and for the elimination of its deleterious products. According to Galen, these substances were excreted by the arterial system; through its terminal branches in the skin and other membranous surfaces on the one hand, and through the *arteria venalis* (pulmonary vein) in the lungs on the other. They consisted mainly of "fuliginous vapors;" that is, volatile products like those from burning fuel.

The same "pulsatile force" which moved the arteries was also active in the heart. The beat of the heart, perceptible through the walls of the chest, was its expansion or diastole, by which it drew into its cavities the blood from the incoming vessels; while its subsequent contraction, or systole, effected an expulsion through the outgoing vessels.†

Galen, Opera Omnia, vol. iii., p. 512; vol. v., pp. 163, 164, 168, 169, 172; vol. ix., p. 7.

† Galen, Opera Omnia, vol. v., p. 164.

Galen devoted much time and study to the mechanism of the heart's movement, which he examined, both with the heart *in situ*, after cutting away the sternum, and in the separated organ immediately after its removal from the chest.* He considered its movements as effected by the alternate or simultaneous action of its different fibres, longitudinal, transverse, and oblique.

"For when, by the contraction of the longitudinal fibres, and the elongation and separation of the rest, the organ is diminished in length and increased in width, at that time you will see that the whole heart is dilated; on the other hand, when the longitudinal fibres elongate, and those situated transversely are drawn together, then the heart is in its systole; and between these motions there is a short interval of quiescence, the heart closely embracing its contents, when all its fibres are in action, but more especially the oblique." . . . . . "Thus the heart dilates, to attract the necessary materials; remains fixed while using what it has drawn into it; and contracts when discharging its superfluities."†

The direction of the fluids, as they enter or leave the heart, was determined by the position of the cardiac valves, all of which were accurately described. On the right side, the tricuspid valves allowed venous blood to enter from the vena cava at the diastole of the heart, and at its systole a portion of the same blood was impelled past the pulmonary valves into the vena arterialis; but both these sets of valves obstructed regurgitation in the opposite direction. On the left side, the mitral and aortic valves acted in a similar

* Galen, Opera Omnia, vol. iii., p. 439.

† Galen, Opera Omnia, vol. iii., p. 439, 440.

way; only Galen maintained, in opposition to Erasistratus, that the closure of the valves was incomplete, thus allowing a certain reflux in each direction. Both the venous blood in the vena arterialis (pulmonary artery) and the arterial blood in the arteria venalis (pulmonary vein) were thought to serve for the nourishment of the lung; this organ, like the rest, requiring a supply of both kinds of blood. But the arteria venalis had furthermore the double office of introducing into the left ventricle the vital spirits derived from the lungs, and of discharging from the blood its fuliginous exhalations. The various acts of reception and delivery were thus accomplished by the cardiac movements, aided by the valves.

But this mechanical action of the heart, according to Galen, was the least important of its functions. For him, as for the older writers, the heart was the centre of organic life, the immediate residence of the animating principle, "the source and, as it were, the fire-place of the innate heat, by which the living organism is directed and controlled" (32). Galen confesses his inability to say what is the nature or essence of this principle of life;* but its immediate manifestation is the vital heat, implanted in the organism from its commencement, with its headquarters in the heart and thence distributed throughout the body. In the different organs and tissues it determines the special acts of growth, nutrition, transformation, and assimilation peculiar to each, which are thus dependent upon it for their continuance and regulation. This vital heat is generated in the heart, and especially in the left ventricle, where it first makes its appearance under the form of

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* Galen, Opera Omnia, vol. iv., p. 472.

sensible warmth. It is communicated to other regions, partly by the venous blood and partly through the solid tissues; but its principal medium of distribution is the arterial blood.*

The functions of the heart and bloodvessels are inseparably connected with the act of *respiration;* and in Galen's doctrine this subject received its due share of attention. The main features of the respiratory process were regarded in the same light as before, but its details were more carefully considered and more clearly explained by him than by any previous writer.

The prime object of respiration was the introduction of the *pneuma*, or spirits, the characteristic ingredient of arterial blood. The inspired air, penetrating into the pulmonary passages, underwent, in the lung tissue, a change which resulted in the production of vital spirits. The spirits accordingly represented, not the substance of the atmospheric air, but something produced from it by the transforming agency of the lung. This aëriform product was taken up by the arteria venalis (pulmonary vein) in the following manner: The terminal orifices of the vessel were "naturally of such size as to be pervious to vapor and spirits, but impervious to blood and fluids of like density." It could therefore take in spirits, or exhale fuliginous vapors, without allowing the escape of blood. The spirits, mingled with the blood of the arteria venalis, could thus be introduced into the left ventricle, and thence transmitted to the arterial blood of the whole body.†

The process of respiration, as described above, consisted in the absorption from the lungs of an unknown

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* Galen, Opera Omnia, vol. v., p. 160.

† Galen, Opera Omnia, vol. iii., pp. 497, 539, 540, 541.

gaseous or "spirituous" substance essential to life, and the discharge of volatile impurities resulting from its action. But how was this supposed to maintain vitality, and in what way was it useful to the living organism?

In Galen's time, as now, there was no other illustration so apt, for the phenomenon of organic life, as that which compares it to a flame; and he discusses the conditions necessary for both, to determine if possible the uses of respiration.

"These ideas," he says, "have no doubt been suggested, in great measure, by what is noticed in regard to flames. Like animals, they quickly perish if deprived of air, as we see in our cupping-vessels (34); and any similar narrow receptacle, which prevents transpiration, will easily extinguish them. If we could find out, therefore, for what reason a flame is smothered under these conditions, we should then know in what way respiration maintains the vital heat." *

In endeavoring to decide this question, Galen enumerates the various causes which favor or impede combustion, such as coolness and warmth, ventilation or fanning, and the supply of fuel. All these, in moderate degree, are useful or essential; but if in excessive quantity, or too rapidly supplied, they repress or extinguish the flame. Every combustive process requires to be fed with combustible material, and it must also be relieved from the accumulation of its smoky impurities. So it is with the vital heat. The blood is the material on which it feeds, and the heart is the wick in which the fuel is consumed. The lung is compared to the containing vessel; but it is a vessel

* Galen, Opera Omnia, vol. iv., p. 487.

perforated throughout, and giving passage everywhere to the incoming and outgoing air.*

"We must therefore admit," he says, "that the function of respiration is to maintain the animal heat. Ventilation and coolness, if moderate in degree, are both serviceable by invigorating the internal heat; and there must also be a movement of expiration, to discharge the smoky matter, as one might call it, derived from the combustion of the blood" (35).

The foregoing sketch presents the main features of Galen's physiology in regard to the organs of circulation and respiration; though it is far from exhausting his many judicious observations and inferences, and his frequent remarks on the correspondence between the structure of an organ and its function. It remains to be seen whether this doctrine included anything which might indicate a circulation of the blood; that is, whether the blood was regarded as moving, in a continuous current, to or from any part of the vascular system or through any portion of its cavities.

There are several passages in Galen's works which, taken by themselves, would seem to imply such a movement. This is especially the case in his description of the origin and distribution of the vena cava, where he compares the bloodvessels to a system of irrigating canals.

"Then the blood is received," he says, "by a single great vein, arising from the convexity of the liver, and extending toward both regions of the body, upward and downward. You would say it was a sort of conduit, full of blood, with a multitude of canals, large

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* Galen, Opera Omnia, vol. iv., p. 491.

and small, running out from it and distributed to every part of the body" (36).

The suggestion is still stronger where he explains how these smaller vessels provide for local nutrition. "This is most easily understood from (the example of) irrigating canals in gardens. A certain quantity of moisture is supplied by them to the parts immediately adjacent, but it cannot reach those which are farther off. Consequently there are numerous smaller water-ways cut from the main one, to provide for the access of water to all parts of the garden; and the spaces between these little canals are of such dimensions as to give them the full benefit of the moisture on each side. So it is with the animal body. Many canals, dispersed through all its parts, convey to them blood, as those of a garden convey moisture; and the intervals separating these canals are wonderfully disposed by nature in such a way that they should neither lack a sufficient quantity of blood for absorption, nor be overloaded at any time with an excessive supply" (37).

This account might readily be supposed to represent the blood as running in a multitude of currents from the centre of the vascular system, through its ramifications, to the periphery. Other parts of the doctrine might bear a similar interpretation; namely, that of the chyle absorbed from the alimentary canal, transported by the portal vein to the liver, and thence distributed, with the rest of the blood, to the system at large; the blood taken into the right ventricle at its diastole, and expelled at its systole into the vena arterialis; a similar discharge from the left ventricle into the aorta; and the declaration that the heart is the origin of the arterial system, as the liver is the origin of the veins. With our present views it would be difficult to admit these facts, without supposing some sort of circulatory movement in the blood.

And yet it is abundantly evident, from Galen's works taken together, that nothing of the kind entered into his conception of the vascular system. For him, the arteries and veins were bloodvessels; but they were vessels for containing blood, not channels for its transportation. He used the simile of irrigating canals without fear of its being misinterpreted or taken too literally. His venous aqueducts were reservoirs of blood, from which a supply might be drawn at any point for the neighboring parts; but it was by a process of transudation or exosmosis, in which each tissue absorbed the requisite materials for its own nourishment. The beating of an artery was not the sign of its distension by an advancing current; it was a spontaneous movement of expansion and collapse, by which the vessel alternately drew into itself materials *from either direction*, and expelled them *toward every point.** As the doctrine of a continuous movement of the blood had not yet presented itself in physiological science, Galen, of course, had no reason to contradict it; and we reach the conviction that it was not recognized in his system, chiefly from the absence or incompleteness of all expressions in regard to it. In the case of the arteries, however, the non-existence of such a current, in our sense of the word, is made plain by his direct statement. Erasistratus had taught that the arteries were filled with aëriform spirits, driven into and through them by the force of the heart; but Galen asserts that, as the arteries contain blood, which is comparatively

* Galen, Opera Omnia, vol. v., p. 164.

dense and sluggish, no such rapid motion is possible. "We have elsewhere shown," he says, "in a special treatise, that the arteries contain blood, even in the normal condition of the animal. This being true, it is plain that the arteries are not, as Erasistratus thought, dilated by the pneuma sent into them from the heart. If they were empty of blood, it might perhaps be possible for what passes into them from the heart to arrive in a short time at their extremities. But if they contain blood, it cannot be that the rapidity of movement corresponds with the notion that they are dilated by being filled from the heart. They are not dilated because they are filled; they are filled because they dilate" (38).

But this mechanical force of dilatation and contraction was not the only one, according to Galen, by which the animal fluids were drawn or impelled in the needful direction. There was also a physiological force, which he compares with that of a magnet,* by which each tissue attracted the ingredients appropriate for its nourishment. By the aid of both these forces combined, all parts of the body, at various times or under different conditions, could draw their nutriment from the common storehouse of the blood; and even the materials which had been distributed to distant regions could be recalled through the same vessels, and delivered to other parts which demanded them for nourishment.† The various organs and tissues are compared in this respect to a number of animals, supplied with fodder in the same field. Some of them are already satisfied, while others are feeding; some

* Galen, Opera Omnia, vol. ii., p. 206.

† Galen, Opera Omnia, vol. ii., pp. 202, 203.

feed together, some separately; some leave off when others begin; and some, who are more famished or more aggressive, will even take away the food from their weaker or less eager companions. Thus the transfer of nutritive material by the blood, in one direction or another, was effected mainly by the accumulation of fluids from the source of supply, and the attraction of each tissue for the substances needed in its growth. It was aided at certain points by the cardiac pulsation and the action of the valves; and a special activity of attraction and expulsion was also kept up throughout the arterial system. This was the idea entertained by Galen as to the process of nutrition and the movement of the blood; and it was the idea handed down by him to the physiologists of later times.

There is still another feature of Galen's doctrine, especially interesting in a historical sense; that is, the *terminal anastomosis between arteries and veins*. This had already been a tenet of the Alexandrian school; but Galen asserted it with greater distinctness, and supported it, moreover, by the evidence of experiment. "The arteries," he says, "anastomose with the veins over the whole body, and they mutually receive from each other blood and spirits, through certain invisible and extremely minute passages" (39). For this reason, the difference in quality between arterial and venous blood is not absolute, but only comparative. Each kind contains both gross and spirituous ingredients; only in venous blood it is the denser elements which preponderate, in arterial blood the finer and more spirituous (40). "For as all the other parts participate in everything, so, too, do the arteries and veins; the former containing blood in small quantity, fine and vaporous, the latter also containing a little spirits, but that cloudy and thick."*

In the doctrine of Erasistratus this anastomosis was assumed, to account for the appearance of blood in a wounded artery. Galen does not admit it on such insufficient grounds; and in his opinion, since the communications are invisible, they need some other reasonable proof of their existence. This proof is not wanting; for when an animal is bled to death by opening the larger arteries, the venous system is also drained of blood, although no vein has been wounded. "The communication between the arteries and veins is never in the large vessels; and their anastomoses are not to be detected by the senses. On that account you might very properly doubt their existence; but you would nevertheless believe in it for the reasons given by former writers, and, not least, from this fact. If you take an animal, like the ox, ass, horse, sheep, etc., in which the veins and arteries are large and easily recognizable, and open several of the principal arteries, you will evacuate from them the whole of the blood. We have often performed this experiment; and, always finding the veins empty as well as the arteries, we are convinced that the dogma of their mutual anastomosis is true."†

That is to say, as the blood of the venous system, in such an animal, finds its exit through the arteries, there must be a communication between them. No communications are to be seen in the larger vessels, where they would certainly be perceptible if they ex-

* Galen, Opera Omnia, vol. iii., p. 450.

† Galen, Opera Omnia, vol. v., p. 165; also a passage to the same effect in vol. ii., p. 207.

isted; they are, no doubt, therefore, in the extreme ramifications, and invisible by reason of their minuteness.

It is remarkable to see this important doctrine, of the terminal communications between arteries and veins, established on such reasonable evidence, fifteen centuries before the microscope and injections revealed them to the eye of the anatomist. It has also a special interest in regard to the lungs. The vascular anastomoses throughout the body were supposed to allow, in some measure, a mutual interchange of blood and spirits between the venous and arterial systems. In the lungs this interchange would be arrested in expiration, were it not for the semilunar valves of the vena arterialis; because this vessel and its branches would be compressed, and its blood forced back into the right ventricle. But since the blood is sustained, even in contraction of the chest, by the semilunar valves, it may still find its way through the anastomoses to the arteria venalis on the opposite side of the lung.*

This interchange of fluids between the bloodvessels of the lungs is, of course, very far from representing what actually takes place in these organs. Like similar actions in other parts of the body, it was regarded as a local occurrence, having little or no influence on the system at large. But it was, nevertheless, a transfer of blood from the veins to the arteries within the lung; and it was aided and guaranteed by the action of the pulmonary valves. Its significance might easily be enlarged without changing its character; and it is evident that the idea of the pulmonary circulation has its roots in the physiology of Galen.

* Galen, Opera Omnia, vol. iii., pp. 453, 454, 455, 456.

Lastly, this part of the subject is connected with Galen's well-known doctrine of the *perforations in the septum of the ventricles.* According to him, the vessels of the lung are not the only channels by which blood finds its way from the venous to the arterial system; it also passes through porosities in the inter-ventricular septum, from the right ventricle to the left.* These perforations are visible in the right ventricle, as funnel-shaped depressions in the substance of the septum; but they are supposed to become so narrow, after penetrating a certain distance, that their orifices on the left side are imperceptible (41). The reasons adduced by Galen, for regarding them as complete channels, were as follows: First, their infundibuliform figure, so far as they were visible, made it likely that their remaining portions were canalicular; since a funnel could be of no use, unless its smaller extremity were pervious. Secondly, of the two vascular orifices on the right side of the heart, that of the vena cava, bringing blood into the ventricle, was larger than that of the vena arterialis carrying it out. It was apparent, therefore, that the blood which entered from the vena cava could not all pass into the vena arterialis; a portion of it filtered through the septum into the left ventricle. This was corroborated by an inverse discrepancy in size between the two orifices on the left side; that of the arteria venalis, bringing spirits from the lung, being smaller than that of the aorta, carrying spirituous blood out. The volume of the blood in the left ventricle was manifestly increased by that arriving, through the septum, from the right side of the heart (42).

By this means a portion of the venous blood became

* Galen, Opera Omnia, vol. ii., p. 208; vol. iii., pp. 495, 496, 497.

arterialized; that is, its finer parts, passing through the septum into the left ventricle, were there amalgamated with the spirituous contents of this cavity, thus completing the formation of the arterial blood. As the products of digestion, accordingly, were elaborated to supply the ingredients of venous blood, so this was afterward elaborated to supply those of arterial blood; or, as Galen expresses it, "what the stomach is to the veins, the veins are to the arteries."

But the channels for the transfer of blood through the cardiac septum were regarded by Galen as of the same nature with the vascular communications in general. He repeatedly mentions them in connection with each other, and he sometimes uses the same word, *anastomosis*, to designate both. The passage of the blood through these communications was not a current; it was a transudation or distillation, drop by drop: and a moderate quantity, thus transferred from the venous system, was sufficient to take part in the generation of vital spirits and the renovation of the arterial blood.

CHAPTER V.

PERIOD OF THE RENAISSANCE.

MONDINI. CARPI. VESALIUS.

THE principal seat of learning in Italy, in the early part of the fourteenth century, was the University of Bologna. At this institution, in the year 1315, the chair of Medicine, which included in its duties the teaching of anatomy, was occupied by MONDINI DA LUZZI. His name is the first, after Galen, of any importance in connection with our present subject; and it marks the point of contact, in scientific matters, between ancient and mediæval times. Mondini has sometimes been called the "restorer of anatomy," because he performed, on two occasions, before the pupils in his lecture room, the dissection of a human body. This would give him but slender claim to such a title, except for the fact that any demonstration in public was at that time an innovation, and because he followed it soon after by the earliest modern work on human anatomy,* presumably founded, in some measure, on his own dissections.

This work had a great success. Notwithstanding its imperfections, it must have contained something which was useful at the time, for it was adopted as a text-book in many, if not all, of the Italian schools of medicine. It continued in use during the whole of the

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* *Mundinus*, De omnibus humani corporis interioribus membris Anathomia.

fourteenth and fifteenth centuries, and was still employed even in the sixteenth.* For a hundred and fifty years it existed only in manuscript. It first appeared in type at Pavia in 1478, only twelve years after the introduction of printing into Italy; and from that time there are enumerated no less than thirteen editions, the last of which was in 1550. The edition of 1513 has a most complimentary preface by the editor, Joannes Adelphus, in which he speaks of Mundinus as "ipse physicus preclarissimus, quem omnis studentium universitas colit ac veneratur ut deum."

The *Anatomy* of Mondini is intended as a manual of dissections, and makes a small octavo or duodecimo volume of seventy-four pages. After a short introduction, which opens with a quotation from Galen, the author, in his first chapter, takes a view of the body as a whole, and is especially interested in pointing out how and why the human body differs from that of other animals. Its most striking peculiarity, namely, its erect posture, he attributes to four causes. First, it is of a lighter, more spirituous, and aëreal substance, and is consequently more easily kept erect. Secondly, it contains a greater quantity of heat, the quality of which is naturally to lift it upward. Thirdly, it has, among all animated creatures, the most perfect form, which it shares in common with the angels and the intelligences which regulate the universe; and fourthly, the sense of sight, through which most of our intelligence comes, needs to be placed at the highest point of the body, like the sentinel on a watch-tower. Among other peculiarities distinguishing man from animals, the one last mentioned is that he has no tail; "because, being naturally

* Sprengel, Geschichte der Arzneykunde, Halle, 1823; vol ii., p. 609.

erect, he rests himself by the sitting posture, and a tail would interfere with his sitting down." The chapter closes with the remark, *Hec sufficiant de anathomia totius.*

The author goes on to enumerate the different regions of the body, giving rules for their dissection and a description of their interior parts; beginning with the abdomen, for the reason that "the organs there are the first to become putrid." He recommends the dissection to be done with a razor (43), making first an incision from over the larynx to the pubes, and then a cross cut at the level of the umbilicus. His description of the organs is very meagre, often hardly indicating more than their general form and position; and much of the book is occupied with the supposed function of the parts, the reasons why they have been made as they are, and the disorders to which they are subject. In the large intestine, mucous and biliary humors, when retained in the sacculi, give rise to tapeworm or cucurbitini, as the case may be. If there is sufficient humor between the adjacent sacculi, it generates a continuous tapeworm; if not, a single worm, or cucurbitinus, is generated in each sacculus.* In the chapter on the heart, the pyramidal or conical form of this organ is accounted for by the fact that it is the source of animal heat, and "because a pyramidal form is the special figure belonging to the principle of heat." The auricles of the heart are most briefly described as "certain additional membranous parts, capable of dilatation and constriction;" but the author explains at some length that they are made for the purpose of relieving the ventricles by their dilatation, "when an unusual quantity of blood is produced in the body, or

* Mundinus, chapter, *De Anathomia intestinorum.*

of spirits in the left ventricle, as sometimes happens." To the objection that nature might have provided for this by making the ventricles larger, he replies that, "as this abundant production of blood or spirits does not take place constantly, if the heart had been very large, much of its cavity would often be empty; while the auricles easily contract when not distended, and so leave no vacancy" (44). He has an equally singular reason for the walls of the left ventricle being thicker than those of the right; namely, that as the blood in the right side of the heart is heavier than the spirits in the left, the parietes of the organ on the left side are made thicker, to counterbalance the weight of the blood on the right (45).

As for the action of the heart and bloodvessels, it is described by Mondini mainly according to the views of Galen, but without any clear or connected statement. His account, always very brief, is sometimes so imperfect as to suggest a doubt whether he fully understood Galen's doctrine. The right ventricle, he says, receives blood from the vena cava and transmits a part of it to the lung by the vena arterialis, while a part passes through the septum into the left ventricle to become spirituous; and the left ventricle receives air from the lung by the arteria venalis, and expels blood and spirits by the aorta to the whole body. But he also enumerates a "middle ventricle," situated in the septum, which is, however, not a single cavity but "many little cavities, wider toward the right side than the left, which gradually refine the blood during its passage, and prepare it for its conversion into spirits." These are evidently Galen's perforations, but the term middle ventricle, as applied to them, is a palpable misnomer;

and the figure introduced as an illustration in the edition of Adelphus certainly does not make the matter clearer. Galen is quoted, on the average, once in every two or three pages. There are occasional references to Averrhoës and Avicenna, and a few to Hippocrates and Aristotle. The style of the book is extremely uncouth; its Latin is barbarous; and its only merit lies in the earnest desire of the author to do what he can for the benefit of his pupils and fellow anatomists (46).

The *Anatomy* of Mondini, and its general use as a text-book, afford a good criterion of the scientific status of Europe during the period of the renaissance; that is, from about the year 1300 to about 1550. At that time both the desire and the capacity for learning were farther advanced in Italy than elsewhere. The most studious and well-informed men in that country had begun to appreciate the literature of the past, and to depend upon it for their own instruction. They saw and felt the intellectual superiority of the ancients, without knowing how to account for it or how to emulate it. This explains their implicit reliance, in medical matters, on the authority and doctrines of Galen; for his works represented to them, not only the learning and talent of their author, but the whole perfected science of an enlightened antiquity.

Consequently, their unquestioning acceptance of Galen's teaching was far from being unreasonable. They were not in a condition to criticise or test; they could only appropriate the knowledge derived from a superior source, and use it for their own guidance. And when an anatomist of more than ordinary enterprise or devotion, like Mondini, illustrated his course by dissections, it was because he wished to see for himself, and show to others, the things described by Galen. If he met with difficulties, they could no doubt be accounted for by the rudeness of his methods and his limited experience. He could neither convince himself nor satisfy others, unless his anatomical demonstrations were in accordance with those of his master; and as for a physiological doctrine, that was, of course, quite beyond the scope of his judgment or investigation. Nevertheless, the work of Mondini has its importance as the earliest anatomical treatise of the middle ages, based, at least in some degree, on the dissection of the human body.

Berengario da Carpi was professor in the university of Bologna two centuries after Mondini; but during that interval the physiology of the vascular system had made no advance. Dissection had been practiced, according to the method of Mondini, in most of the European schools, without leading to any noticeable discovery or improvement. Carpi, who was distinguished both as surgeon and anatomist, is said to have dissected for his own purposes an unusually large number of subjects; and his results are embodied in a treatise* first published at Bologna in 1514, and afterward reprinted in that and various other places. This work, like that of Mondini, has the form of a manual for dissections, and is arranged in a similar manner. It is rather more copious than its predecessor, and its statements are somewhat better expressed; but they do not differ in any important particular from those of the

* Isagogæ breues plucidæ ac uberrimæ in Anatomiam humani corporis a communi Medicorum Academia usítatam a Carpo in Almo Bononiensi Gymnasio Ordinariam Chirurgiæ docente ad suorum Scholasticorum p̃ces in lucem datæ. Bononiæ, 1523.

former work. In many instances the language of Carpi is almost a paraphrase of that employed by Mondini. He offers the same explanation of the thickness of the left ventricle as compared with the right, namely, the necessity for counterbalancing the greater weight of the blood in the right cavity; and the use of the auricles, according to him, is still to provide for the occasional superabundance of blood or spirits, so that the ventricles might not be too large. He differs from Mondini as to the significance of the pyramidal form of the heart, which, he thinks, "is not principally because as a source of heat it assumes the peculiar figure of fire;" but his own interpretation is hardly more intelligible (47). The point of the organ, he says, is made small because this part, lying in contact with the walls of the chest, is the one likely to be injured during its movements, "and consequently the smaller it is, the less injury will be received." He mentions the report that men have sometimes been born with the heart covered with hair, on which account they were braver than other people; and cites, on Pliny's authority, the case of Aristomenes, a Messenian, who killed three hundred Spartans, and, when wounded and captured, exhibited such extraordinary and persistent audacity that the Spartans opened his chest to discover its cause, when they found that his heart was hairy. At the end of the book the author excuses himself, on account of other unavoidable occupations, for not having made it more extensive; and in case his readers are not satisfied, he refers them to his "very full commentaries on the anatomy of Mondinus."

It seems that the progress in anatomical knowledge since the fourteenth century, if any there were, could only have been connected with very ordinary details, like the ramification of nerves and bloodvessels; for there was no difference in the general treatment of the subject, nor in the mode of inferring the function of a part from its structure. The physiology of Carpi, so far as regards the heart and bloodvessels, is a repetition of that of Mondini; except that some things are stated with greater clearness and in a more attractive way. The action of the cardiac valves; the ingress and egress of blood and spirits by the different orifices; the filtration of blood through the septum into the left ventricle; the passage of air for the generation of vital spirits through the arteria venalis to the heart; and the discharge of fuliginous vapors into the lung by the same channel, are all given without modification, and evidently without any idea of testing or even of questioning their reality. The anatomist was satisfied with the commonest exposition of the form and connection of the parts, and with a very incomplete description of their texture. Their physiological action, except so far as known on the authority of the ancients, was a subject only for inference or surmise.

But a short time after Carpi, anatomy received a fresh impulse from the scientific zeal and ability of Vesalius. His appearance in the sixteenth century makes an epoch in the history of medicine; for he placed its most fundamental department on a different footing from that which it had occupied before. He was the first to treat anatomy as a science to be studied and taught by itself, and as worthy of a devotion commensurate with its importance and extent. As he originated the idea, so he gave to its execution an industry and intellectual capacity above the average. One cannot help thinking of his predecessors as men who owed much of their celebrity to the imperfect knowledge of the times and the absence of competition. But this will not apply to Vesalius. In any age and in any country, he would have taken the highest rank as a scientific investigator; and the remarkable development of anatomy during the remainder of the century was largely due to the effect of his influence and example.

Vesalius was born in 1514, at Brussels, the principal city in the Netherlands, at that time, next to Italy, the most populous, the wealthiest, and most cultivated portion of Europe. After receiving a classical education, he began his medical studies at a very early age, pursuing them at the academies of Louvain and Montpellier, and finally at Paris, where he attended for three years the lectures and demonstrations of Sylvius (48), then the most celebrated professor in the Parisian schools. While here, the instinctive readiness and activity of Vesalius began to show themselves. His dexterity and success in dissection became equal or superior to those of his master; and before the end of his course he was more than once invited, by both professors and students, to conduct anatomical demonstrations in public. He was also for some time a pupil of Joannes Guinther of Andernach, whose manuscript lectures he edited in 1536; and he afterward taught anatomy, probably as a private enterprise, at his alma mater, the academy of Louvain.

His reputation had by this time extended so far, that in 1537 he was called to the professorship of anatomy and surgery in the university of Padua, in which chair he continued for nearly seven years. In addition to his duties at Padua, he was soon after invited to teach anatomy at Bologna, and finally also at Pisa; giving his course successively during the same winter in each of the three universities. His industry and devotion were rewarded by an increased facility in obtaining anatomical material. While at Paris he, with his companions, made nocturnal excursions to the cemetery of Montfaucon, to collect bones for the formation of a skeleton; and while a teacher at Louvain, he despoiled by night the gibbet of a malefactor for the same purpose. But at Padua and Bologna he was supplied with subjects by the voluntary exertion of his pupils; and on his appointment at the university of Pisa, the Duke Cosmo dei Medici legalized the appropriation of bodies from the public cemetery for purposes of anatomy (49).

While professor at the university of Padua, he published his earliest and most important work, on the Structure of the Human Body,* which advanced the science of anatomy at a single step, farther than it had progressed for several centuries. The book of Carpi, published less than thirty years before, will bear no comparison with that of Vesalius. It is a small quarto of eighty pages, of inferior scope and execution, illustrated with a few coarse woodcuts, the most important of which are quite beneath criticism. The work of Vesalius is a well printed folio of six hundred and seventy-eight pages, with a copious index and a large number of correct, instructive, and artistic illustrations. The full-length figures were engraved from designs by John de Calcar, one of the best pupils in the school of

* Andreæ Vesalii de Humani corporis fabrica Libri septem. Basileæ, 1543.

Titian, whose pictures are said to have been often mistaken, by good judges, for those of Titian himself.* A second edition, printed at Basle, under the author's revision, in 1555, is still more carefully executed, and is a magnificent specimen of the printer's art.

There is an equal difference in style and method between Vesalius and his predecessors. Mondini and Carpi are both denizens of the middle ages; but Vesalius is a modern. He treats his subject from the outset in a direct, comprehensive, and systematic way. He sees the end of his work from the beginning; and he leaves no room for doubt, as to the originality of his plan, his reasons for adopting it, or the sources of his knowledge. When we see, from the dates engraved on the frontispiece, that this work, the first of its kind, was written and published by a mantwenty-eight years of age, it seems hardly less than phenomenal. It was republished, one hundred and eighty years afterward, by Boerhaave and Albinus,† who speak of it, in their preface, as "opus incomparabile anatomicum, quod periturum nunquam, omnis ævi tempore præclarissimum habebitur omnium quæ in hanc usque horam ab ullo mortalium edita fuerunt."

Vesalius represents the first attempt of scientific medicine in Europe to emerge from its condition of tutelage. Until that time, professors and practitioners alike were simply the disciples of Galen. His writings were to them the fountain of knowledge, as unquestion-

* Vasari, Vite de' piu' eccellenti pittori, Milano, 1807, vol. x., p. 234; and Biographie Universelle, Paris, 1812; article, Calcar.

† Andreæ Vesalii Opera omnia anatomica, & chirurgica. Cura Hermanni Boerhaave & Bernhardi Siegfried Albini.

Lugduni Batavorum, 1725.

able as holy writ; and their highest ambition was to study his books and understand his doctrines. Vesalius shared this feeling so far as to appreciate the indispensable value of the works of Galen, whom he calls the "prince of physicians," the "chief of anatomists," and the "author of all good things." But he had also the instinct of investigation, and a practical belief in its results. In his dissections he met with various details, not in accordance with the descriptions of Galen; and on repeating his observations, and comparing them carefully with the text, he at last reached the conviction that Galen's anatomy was not the anatomy of the human body, but was founded mainly on the dissection of animals.* This conviction, once established, left him free to describe the parts according to his own observation, and gave him a greater stimulus to do so; for his own work was devoted exclusively to the "structure of the human body," while Galen's was rather a "general anatomy and physiology" of the higher animals.

The assertion that Galen's descriptions were not entirely accurate, as applied to human anatomy, was received with great disfavor. It seemed to impugn the authority from which everything of value in medical science had been derived; and it was resented by some as a treason to medical science itself. The age was not yet quite ready to admit the possibility of imperfection in its ancient doctrines; and the idea, that Galen's dissections were practiced only on animals, continued to meet with disbelief and opposition from many prominent men of the time. It is now generally acknowledged to be true (50); and its announcement in

* Vesalius, De humani corporis fabrica, Præfatio.

the sixteenth century was the earliest movement toward emancipating the profession from its blind subserviency to the text of a standard author. Vesalius himself may be partly responsible for the incredulity of his contemporaries. His criticisms of Galen are perhaps repeated with unnecessary frequency; and he sometimes appears to take for an error what is only a different way of viewing the subject, equally legitimate with his own (51). But he has the great merit of an absolute and abiding faith in the direct observation of nature as a source of knowledge, and its superiority in value to any scientific tradition, however widely accepted.

The doctrine of Vesalius, in regard to the heart and bloodvessels, is, except in one particular, the same with that previously in vogue; but it is presented by him in a remarkably graphic and intelligible style. The venous blood, formed in the liver from the chylous juices brought by the portal vein, is the nourishing material for the substance of the tissues. By the vena cava, it enters the right side of the heart, whence a portion of it is distributed to the lungs by the vena arterialis. But the heart is especially the centre of life, and the focus of animal heat; and in its left ventricle the blood, elaborated and united with the aëriform product of the lung, becomes fine and spirituous, and fit for distribution by the arterial system. The pulsations of the heart are due to its three sets of fibres; of which the longitudinal effect its dilatation, drawing the blood into its cavities; the transverse or circular cause its contraction, and expel the blood; while by the oblique, its contents are momentarily retained for elaboration. The arterial pulsation is a similar movement of expansion and contraction ; a kind of general respiration or ventilation throughout the body, in which the vital spirits reanimate or rekindle the innate heat of the parts.

The single point in which Vesalius differs from the classical doctrine is an important one; namely, that of the passage of blood, through the cardiac septum, from the right ventricle to the left. He does not admit the perforations in the septum, described by Galen. He is well acquainted with the pits or depressions on its surface; but they exist, also, he says, in other parts of the ventricles ; and they do not, so far he can perceive, lead to any passages through which blood could find its way.

"The surface of each ventricle is extremely uneven, and beset with numerous pit-like indentations, deeply sunk in its fleshy substance. These pits, however, are not confined to the side by which the right ventricle corresponds with the left (notwithstanding it is so understood by all other anatomists), but are found over the whole ventricular surface. They are apparent, not only in recently killed animals, but also in the preserved heart, as long as it is kept; and even in the desiccated organ they still remain open. But however conspicuous these depressions may be, none of them, so far as perceptible by the senses, penetrate through the septum from the right ventricle into the left. Nor do I find even the minutest channels which would make the septum pervious, although such perforations are described by anatomical professors, who believe implicitly in the passage of blood from the right ventricle to the left. I am therefore in no little doubt as to the function of this part of the heart" (52).

The doubt here expressed by Vesalius is a very serious one. The blood, he says, which enters the right ventricle from the vena cava is destined to supply, "not only the heart itself and the lungs, but also *all the arteries*, which, we believe, are filled with blood from the heart."* He knows, therefore, that, in some way or other, blood must be transferred from the right ventricle to the left; and yet its passage through the septum, acknowledged by all the anatomists of his time, seems too hypothetical to satisfy him. He remembers, it is true, that the extremities of the portal vein absorb their chylous juices from the alimentary canal through passage-ways that have never been seen. He will not, therefore, hazard a positive denial in regard to the septum of the ventricles; but he prefers to remain in doubt, rather than adopt an opinion with so little evidence in its favor. At all events he declares, that the supposed perforations in the septum do not exist in the form and with the distinctness that anatomists have asserted and believed.

"In recounting as above," he says, "the structure of the heart, and the use of its different parts, I have followed in the main the doctrines of Galen; not that I regard them in all particulars as consonant with the truth, but because, in attributing new functions and uses to a number of parts, I am still distrustful of myself, and not long ago should hardly have ventured to differ from that prince of physicians by so much as a finger's breadth. As for the dividing wall or septum between the ventricles, forming the right side of the left cavity, the student of anatomy should consider carefully that it is equally thick, compact, and dense,

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* De Humani corporis fabrica, liber iii., cap. vii.

with all the rest of the cardiac substance enclosing the left ventricle. And accordingly, notwithstanding what I have said about the pits in this situation, and at the same time not forgetting the absorption by the portal vein from the stomach and intestines, I still do not see how even the smallest quantity of blood can be transfused, through the substance of the septum, from the right ventricle to the left" (53).

Vesalius accordingly finds the door in the septum of the ventricles closed; and he does not indicate any other route by which the blood might pass from the right side of the heart to the left. But there are two points which present themselves to the reader of Vesalius, which are very noticeable in this connection. The first is that he, as well as other anatomists, already knew the circulation through the liver; or at least they believed in some communication between the portal and hepatic veins. The classical doctrine had long recognized the transfer of blood as an elaborated product through the liver from the portal vein to the vena cava; but it was stated by Vesalius more distinctly than before. "The branches of this vein" (vena cava), he says, "distributed through the body of the liver, come in contact with those of the portal vein; and the extreme ramifications of these veins inosculate with each other, and in many places appear to unite and be continuous" (54). Thus, at least in one of the vascular organs, a way seemed open for the passage of blood, by vascular continuity, from one set of vessels to another.

Secondly, it is evident, from the language of Vesalius, that the perforation of the cardiac septum was not the only thing which he held in doubt. There were several peculiarities in the arrangement of the vascular system not clearly explained by the existing doctrine; and some of his expressions are so pointed as to be extremely suggestive in the light of our present knowledge.

"When these matters are taken into account, many things at once present themselves in regard to the arterial system which deserve careful consideration; especially the fact that *there is hardly a single vein going to the stomach, the intestines, or even the spleen, without its accompanying artery*, and that nearly every member of the portal system has a companion artery associated with it in its course. Again, the arteries going to the kidneys are of such a size that they can by no means be affirmed to serve merely for regulating the heat of these organs; and still less can we assert that so many arteries are distributed to the stomach, intestines and spleen for that purpose alone. And there is, furthermore, the fact, which we must for many reasons admit, that there is through the arteries and veins a mutual flux and reflux of materials, *and that within these vessels the weight and gravitation of their contents has no effect*" (55).

Vesalius was evidently impressed with the idea that in several particulars the accepted physiology of the vascular system was an inadequate expression of the truth. If he did not say more about them, it was because his opinions were too incomplete or uncertain for definite statement. But when we remember his intellectual activity and independence of mind, we can readily believe that continued research would have led him to more positive results. If Vesalius had remained professor of anatomy at Padua, instead of being called to be court physician at Madrid (56), it seems quite within the bounds of probability that the circulation of the blood might have been discovered in the sixteenth century.

CHAPTER VI.

SERVETUS.

THE most singular episode in the history of the circulation is that of the existence and writings of Servetus. He was unlike any other character among those who took part in its development or discovery. He had no apparent connection with any predecessor or any follower. He dealt with one of the most important questions in physiology, and yet he was a theologian and a heretic more than a physician or anatomist. His tragic fate adds to the strangeness of the interest that surrounds him; and his book, after being interdicted and suppressed in the sixteenth century, was resuscitated in the eighteenth as an ecclesiastical and medical curiosity.

Michael Servetus was born in Spain about the year 1510; but there is a doubt as to the exact date and place of his birth, one account making him a native of Tudela in Navarre, the other of Villaneuva in Arragon. There is a similar uncertainty in regard to his early life and education. He is thought to have been a pupil in the university of Saragossa, and afterward to have entered as a student of law at Toulouse; and he was for a time attached in some capacity to the service of Quintana, father confessor to the emperor, Charles V. But his first appearance in any definite character was in the year 1530, when he became known by his correspondence and interviews with the Swiss and German Reformers. Servetus was then only about twenty years of age, but he was so absorbed in questions of controversial theology that he was bent on discussing them with the leaders of the Reformation; and in the following year he published a book on the "Errors of the Trinity,"* which excited great animadversion on account of its alleged heretical doctrines. It was denounced and condemned by both Protestant and Catholic authorities; and Servetus found himself obliged to withdraw from the field, to avoid the consequences of his temerity.

He then went to Paris, and under the assumed name of *Michel Villeneuve* entered as a student at the University, where, four years afterward, in 1536, he graduated as Doctor in Medicine. His first essays, however, in his new profession were but little acceptable to the medical faculty; since he attracted attention by public lectures on Geography and Astrology, and in his practice was said to employ largely the casting of nativities and astrological divination. When cited before the Medical Council and reproved for these irregularities, he printed in reply a pamphlet,† in which he defends the science and art of astrology with much dialectic ability, and characterizes his critics as "sophists," who have "demonstrated nothing except their own ignorance." But the case having been brought before the Parliament of Paris, Servetus was ordered to withdraw his pamphlet from publication, and to refrain in future from the teaching or practice of astrology or divination.

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* De Trinitatis Erroribus, 1531. The book did not bear the imprint of publisher, printer or place of publication.

† Michaelis Villanovani in quendam medicum apologetica disceptatio pro astrologia, Parisiis, 1538. Reprint by Henri Tollin, Berlin, 1880.

He also published a treatise on the action of medicinal syrups, entitled "Syruporum universa ratio, ad Galeni censuram diligenter explicata," which was mainly a citation and comparison of the views of older writers on this subject, and which does not seem to have contained anything especially remarkable in medical doctrine. Not long afterward, about 1540, he gave up his residence in Paris, and established himself as physician in the archiepiscopal city of Vienne, in the south of France, still under the name of Michel Villeneuve, by which he was exclusively known. Beside the attention which he gave to medical practice, he occupied himself to a considerable extent as proof-reader and corrector for the publishing houses of Lyons and Vienne; and under their auspices acted as editor and annotator for several non-medical books of some importance. His fancy, however, for theological controversy was as strong as ever, and soon led him into a correspondence with Calvin, then the most influential personage in Geneva and the acknowledged head of the Swiss Reformers. The correspondence turned out to be mutually unsatisfactory, and produced on both sides no little acrimony of feeling. Servetus then applied himself to writing a book, in which his views should be set forth in full, and which he finally printed, secretly and at his own expense, in a private house at Vienne (57).

It was this book, the "Christianismi Restitutio," which was the principal production of Servetus' life, and also the cause of his death. As its name implies, it was a plea for the restoration of Christianity to its original form, which, Servetus thought, had been altered and corrupted since the time of the early churches.

But this reformation was not one of morals or practical Christianity. It was concerned mainly with abstruse questions regarding the Father, Son, and Holy Spirit, and their relations to the doctrine of the Trinity. Servetus considered these questions sufficiently important to absorb most of his interest and attention, and to justify the dangerous experiment of issuing his opinions in printed form. In their discussion, however, his metaphysical distinctions are often so finely drawn, or so obscurely expressed, that they are practically unintelligible to all but experts in theological technicalities (58); and to the ordinary reader he sometimes appears to destroy in one paragraph the meaning expressed in another. His sincerity and enthusiasm cannot be doubted; and at the present day it seems difficult to conjecture why Servetus should have ventured so much for the promulgation of these intangible abstractions, or why his opponents should have considered them, when printed, as dangerous to the public welfare.

In this book Servetus, most unexpectedly, announces the physiological doctrine that the transfer of blood, from the right side of the heart to the left, takes place through the lungs and not through the septum of the ventricles. The passage occurs in a part of the volume where Servetus is treating of the Holy Spirit, which he considers as the mode of communication from the Deity to man; and in this connection he offers an exposition, or what he calls a "divine philosophy," of the life and spirits in the corporeal frame. After giving the usual account of the vital spirits as produced in the heart, and the animal spirits in the brain, he proceeds to explain how it is that the life, or soul, is not seated in the substance of the solid organs, but in the blood, and that the life itself is the blood, or the sanguineous spirit, as taught by Holy Writ.

"To this end," he says, "we must first understand the substantial generation of the vital spirit, which is formed and nourished from the inspired air and the finest part of the blood. The vital spirit originates in the left ventricle of the heart, the lungs taking a very important part in its generation. It is a thin spirit, elaborated by the power of heat, of a bright golden hue and fiery potency;—as it were, a transparent exhalation from the purer kind of blood, containing in itself the substance of water, air, and fire. It is generated from the mixture made in the lungs between the inspired air and the finely elaborated blood which the right ventricle of the heart communicates to the left. *This communication, however, does not take place through the median wall of the heart, as commonly believed; but, by a grand device, the refined blood is driven from the right ventricle of the heart, in a long course, through the lungs. By the lungs it is prepared, assuming a bright color, and from the vena arteriosa is transferred into the arteria venosa.* Then, in the arteria venosa itself, it is mingled with the inspired air, and purged of its fuliginous matter by expiration. And so, at length, the left ventricle of the heart attracts by its diastole the whole mixture, a suitable furnishing material, that it may become vital spirit.

"That the communication and preparation takes place in this way, through the lungs, is shown by the varied conjunction and communication of the vena arteriosa with the arteria venosa in the lungs. It is confirmed by the remarkable size of the vena arteriosa, which would not have been made either of such construction or so large, and would not convey from the heart such an abundance of blood into the lungs for their nourishment alone, nor would the heart supply the lungs in this way; especially as at an earlier time, in the embryo, the lungs themselves were nourished from another source, owing to those membranes or valves of the heart which are not closed until the hour of birth,* as Galen teaches. Consequently, it is for another purpose that the blood is poured from the heart into the lungs at the hour of birth and in such abundance. Moreover, it is not simple air which is sent from the lungs to the heart through the arteria venosa, but air mixed with blood; therefore, the mixture takes place in the lungs. The bright color is given to the spirituous blood by the lungs, not by the heart. In the left ventricle of the heart there is not sufficient space for so great and copious a mixture, nor an elaboration capable of producing that bright color. And, finally, the median wall, having no vessels or vital endowments, is unfit for such a communication and elaboration, though something may possibly transude through it. *By means of the same device, which in the liver makes a transfusion from the portal vein to the vena cava for the blood, there is in the lung a transfusion from the vena arteriosa to the arteria venosa for the spirit.* Whoever compares this with what is written by Galen, in the 6th and 7th books De Usu Partium, will comprehend a truth not noticed by Galen himself"(59).

Certainly nothing could be more distinctly stated than this. The obscurities met with elsewhere in the writings of Servetus have no place here. The reader

* That is, the valve of the foramen ovale.

is not for a moment in doubt as to what he means; and if his idea needed any further explanation, it is fully supplied by his admirable comparison of the transfusion through the lungs, for the formation of arterial blood, with that through the liver for the formation of venous blood. Moreover, he is perfectly well aware that his doctrine is a new one, although he announces it with entire confidence; and he refers to Galen's opposite views in a way almost disdainful, as if it were hardly worth while to discuss the correctness of his own opinion as against the great teacher of antiquity.

This makes it the more remarkable to find so important a physiological doctrine announced in a volume like the "Christianismi Restitutio." The book of Servetus was not addressed to medical readers, but to ecclesiastical reformers and schismatics. It could not be expected to have a circulation in France, or in any other Catholic country; and those whom it might reach in Germany or Switzerland would care but little about the transfusion of blood through the lungs, in comparison with the niceties of trinitarian metaphysics. It would seem natural for so ambitious a man as Servetus, in possession of such a physiological novelty, to declare it as his own discovery to the medical world and establish it as the doctrine of the time. Instead of that, it is inserted, as a matter of secondary consideration, in a book on a different subject, secretly printed for distribution abroad, and to which the author could not venture to append his name.

Perhaps these incongruities may be accounted for in part by the erratic character of Servetus, and the singularity of his ideas, which was as remarkable in the domain of physiology as in that of religion. We should have a very imperfect idea of Servetus as a physiologist, if we were to confine ourselves to his brief passage on the transfusion of blood through the lungs. This is only a part of his "divine philosophy" as to the nature of life, spirit, and soul, and their mode of existence and generation in the body. In the further elaboration of this philosophy, he so intermingles the ideas of life, soul, mind, vital spirits, animal spirits, breath, inspiration, and even of the Holy Ghost, that it seems uncertain whether he regards either of them as an incorporeal being or force, or as a material vapor that may be taken in through the nostrils and contained in the cavities or vessels of the body. This obscurity reaches its climax when he treats of the ventricles of the brain and the vessels of the choroid plexus, containing the animal spirits, and, as he asserts, the "very mind itself" and the soul, which is fanned, like a flame, by the air inspired into the ventricles through the ethmoid bone.

"In the second place," he says, "the ventricles are for this purpose, that a portion of the inspired air, penetrating into their vacant spaces through the ethmoid bones, and attracted by diastole into the vessels of the soul, may renew the animal spirit contained within them and ventilate the soul (anima). In these vessels is the mind, soul, and fiery spirit, which requires a double flabellation (that is, a to-and-fro fanning, or ventilation from without inward and from within outward); otherwise it would be smothered, like an external fire in a closed place. It needs, like a fire, inward and outward ventilation, not only to get its pabulum from the air, but also for the discharge of its fuliginous matter. As the external elementary fire unites with a dense earthy substance, owing to the quality of dryness and the form of light common to both, having for its pabulum the moisture, and is ventilated, maintained, and nourished by the air: in like manner this igneous spirit and soul of ours is associated with the body, making one with it, having the blood for its pabulum; and by the aërial spirit, in inspiration and expiration, is ventilated, maintained and nourished, so that it has a two-fold aliment, spiritual and corporeal. By reason, therefore, of its locality and of its spiritual nourishment, it is most appropriate that this same lucid dwelling place of our spirit should receive the afflatus of another, sacred, celestial, lucid spirit, by expiration from the mouth of Christ, as we by inspiration draw our spirits into the same place. It is fitting that the same place which is the seat of our intelligence and luminous soul, should be illuminated anew by the light of another celestial fire. For God lights in us the first lamp, and the shadows that spring up there he again turns into light, as saith David, Psalm xvii, and II. Samuel, 22, also Elihu, in Job xxii. and xxxiii. The same thing is taught by Zoroaster, Trismegistus and Pythagoras, as I shall cite presently. Moreover, a good formation and temperament of the vessels conduces to goodness of mind, so that those persons have a better soul in whom the disposition of the parts is a good one. But as this indwelling light is more and more illuminated by a good spirit, so it is obscured by a bad one. If into those vessels of the brain, together with our lucid animal spirit, a dark and bad spirit intrudes itself, then you will see demoniacal ravings, as by a good spirit come lucid revelations. But these vessels are easily attacked by the evil spirit which has its seat near by, in those watery abysses and cavities of the ventricles of the brain. This evil spirit, whose power is of the air, goes freely in and out of those cavities, to contend there unceasingly with our spirit, dwelling within those vessels as in a citadel. And it so besets our spirit on all sides that it can hardly breathe, unless when the supervening light of the spirit of God puts the bad spirit to flight. How appropriate to that place is the constitution of mind, spirit, revelation and intelligence, and the fight with higher temptations, to say nothing of the others!" (60).

Throughout this part of his treatise, Servetus makes no distinction, as to the certainty of his opinions, between those which have turned out to be well founded and those which are chimerical. His account of the mode of communication, in the lungs, between the two sets of vessels, is very striking; where he says that it is by "another kind of vessel, formed from the vein and the artery," as if he had divined the existence of the pulmonary capillaries. But in describing the small arteries of the brain and their communication with the nerves, he speaks with the same confidence of "another kind of vessel" here also, through which the animal spirits are conducted from the terminal arteries to the nerves; and the nerves "retain in their interior cavity, a membrane common to themselves and to the above mentioned vessels, for the safe custody of the spirit."* In his chapter on Faith, he has also a discussion to show that faith is in the heart, and that the heart is free, notwithstanding that the source of volition and action, according to Galen, is in the brain; because the animal spirits of the brain are formed from the vital spirits of the heart, and in the

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* Christianismi Restitutio, p. 172.

heart, accordingly, is the prime origin of the life and soul.*

Even if Servetus' book had come to the knowledge of the medical world, it is doubtful whether a doctrine accompanied by so many extravagances would have found favor with the profession. But it was destined to meet with immediate suppression from another source, and to pass, with its author, into the oblivion of a century and a half. The printing of the "Christianismi Restitutio" was completed, without the knowledge of the authorities, in the early part of 1553; and a copy was sent, either by Servetus or by one of his friends, to Calvin at Geneva, in the hope that it might recommend itself to so determined an opponent of the Catholic Church. But the Reformer, instead of being pleased, was shocked at its contents. He recognized the polemical style and heretical ideas of the author of the former book "De Trinitatis Erroribus," and also of his recent correspondent Villeneuve, now seen to be one and the same person. He caused information of these facts to be transmitted to the authorities at Vienne, who at once arrested and examined Servetus and his printer, but without as yet discovering where the books were concealed. Servetus embraced the first opportunity of escaping from prison, and made his way to Geneva; intending, it is said, to pass from thence into Italy. But while at Geneva he was recognized, denounced, imprisoned, and arraigned for heresy; and, after a trial which lasted over two months, was condemned to be burned at the stake. This sentence was carried out on the following day, October 27th, 1553; and his books, which had been

* Christianismi Restitutio, p. 301.

discovered in the meantime, some in France and some in Germany, were also burned by the public executioner. It does not appear that they had yet been offered for sale; and not more than four or five were retained by the legal authorities for use in the prosecution. At the present day, there are only two copies of the original work known to be in existence; namely, one in the National Library at Paris, the other in the Imperial Royal Library at Vienna. The passage on the pulmonary circulation was quoted for the first time, in an English book,* in 1697; and in 1790 a small edition of the entire work was reprinted in fac-simile from the Vienna exemplar. It is from a copy of this reprint that the foregoing quotations have been made.

The story of Servetus is most interesting as a psychological study, and also as the instance of a remarkable physiological truth first stated by an author who afterward remained unknown until the doctrine of the circulation had advanced far beyond its condition as understood by him. In his announcement of the transfer of blood through the lungs, Servetus jumped to a conclusion which Vesalius hesitated to adopt; but it was overshadowed by the number and importance of other topics in the same volume; and the book and its author were both forgotten, when the short-lived interest in his trial had passed away (61).

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* Wotton, Reflections on Ancient and Modern Learning, London, 1697, p. 229.

CHAPTER VII.

DAWN OF THE CIRCULATION.
COLOMBO. CAESALPINUS. FABRICIUS.

THROUGHOUT the sixteenth century, the principal centres of medical learning, and the headquarters of medical progress and discovery, were in Italy. The universities of Padua, Pisa, Pavia, Bologna and Rome, all had their medical professors, attracting students and teachers from every direction; and during this period most of the names, permanently connected with the advancement of anatomical science, were those of native or resident Italians.

COLOMBO was in his earlier years an apothecary in the city of Cremona, where his father was engaged in the same occupation. He afterward entered as a pupil in the university of Padua, and there pursued the study of anatomy under the instruction of Vesalius. In this department he became so proficient that in 1544 he succeeded his master in the vacant chair of anatomy, going soon afterward in the same capacity to Pisa, and finally to Rome, and teaching anatomy in each of these places with acknowledged success. The result of his labors is embodied in a treatise * published in 1559, immediately after the death of the author. On the last leaf is the imprint of *Frater Felix Perettus*, *Hæreticæ pravitatis Inquisitor*, certifying that he has duly read

* De Re Anatomica Libri xv. Venetiis, MDLIX.

the book and found in it nothing contrary to the Catholic faith, good morals or principles.

Colombo's book is a handsome quarto, of two hundred and seventy pages. It bears, throughout, the marks of the example and teaching of Vesalius. It is systematically arranged, treating, in successive divisions, of the bones, cartilages, ligaments, muscles, the liver and veins, the heart and arteries, the nervous system, and the viscera. Colombo follows his teacher in declaring his independence of Galen, whom he asserts, on similar and sometimes the same * grounds, to have confined his dissection to animals. He does not hesitate, upon occasion, to question the opinions of Aristotle, and even of Hippocrates; and he frequently differs with Vesalius, whose supposed errors or omissions he points out with unsparing hand. But where a leader has once shown the way, it is easy for a follower to see the deviations of his track; and while Colombo is no doubt entitled, in some cases, to the credit of improving upon the account given by Vesalius, his improvements relate, for the most part, to matters of detail. At the end of the volume, as in that of Vesalius, there is a chapter on vivisections, showing the reasons for their usefulness, the proper mode of preparing the animal, and conducting the operation, for studying the motions of the diaphragm, lung, heart, and arteries, the existence of the pericardial fluid, and the functions of the nerves; and though there are no anatomical plates, properly speaking, the ornamental headings of the chapters, and even the elaborate frontispiece, representing the anatomist demonstrating to

* Compare Vesalius, lib. vi., cap. vii.; and Colombo, lib. xi., cap. ii., on the pulmonary lobes.

his audience from a human cadaver, are plainly in imitation of his teacher's larger work. The book is written in a style not precisely elegant, but very clear and simple; and in many instances the descriptions which it contains are both more concise and more intelligible than those of any previous writer.

The important feature in Colombo's work is his doctrine of the conversion of venous into arterial blood in the lungs, and its delivery thence by the arteria venosa to the left ventricle of the heart; that is, of the pulmonary circulation. This doctrine he states repeatedly, with his accustomed force and perspicuity, in his chapters On the Heart and Arteries and On the Lung, as a matter of great importance, which "no one has ever before observed or mentioned," or "even hinted at."

"Between the ventricles of the heart," he says, "there is a septum, through which, as nearly all believe, there is a passage for the blood from the right ventricle to the left, in order that it may be refined, during its transit, for the generation of the vital spirits. But in this they are very far from the truth; for the blood is carried through the vena arteriosa to the lung and refined there, and thence, together with the air, it is brought away by the arteria venalis, to the left ventricle of the heart" (62). "These three vessels, accordingly (namely; the trachea, the vena arteriosa, and the arteria venosa), are surrounded by a light, thin, and porous substance; thus making up the tissue of the lung, which has for its function, as correctly taught by anatomists, first, the refrigeration of the heart by means of the cool air thus introduced, and furthermore, the act of inspiration and expiration for the formation of the voice.

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These uses of the lung are already known to former writers. Beside them, I now add another of the greatest importance, to which no one has ever alluded even by a hint; that is, the preparation, and all but generation, of the vital spirits, which are afterward more thoroughly perfected in the heart. For the air, inspired through the mouth and nostrils, and disseminated by the trachea throughout the pulmonary substance, is mingled by the lung with the blood brought to it from the right ventricle of the heart through the vena arterialis. This vein, indeed, beside bringing blood for the nourishment of the organ, is large enough to bring blood also for another purpose. The venous blood, agitated and refined by the continual motion of the lungs, is mingled with the air, which has been also prepared by the same collision and comminution; so that the intermingled blood and air are taken up together by the branches of the arteria venalis, and finally conveyed through its trunk to the left ventricle of the heart. There they arrive in a condition of such complete mixture and attenuation, that there is but little further for the heart to do; and when that little is accomplished, giving, as it were, the last touch to the vital spirits, it only remains for the heart to distribute them, by means of the aorta, throughout the body" (63).

The main innovation in the doctrine of Colombo is plainly the transfer of the important operation of vitalizing or arterializing the blood from the heart to the lungs. It was understood by all that the vital spirits resulted from a mixture of air from the lungs with blood from the venous system. According to the older doctrine, this intimate union and generation took place in the left ventricle of the heart; the air, received and elaborated by the lungs, being conveyed thence by the arteria venosa (pulmonary vein) to the left ventricle, and there united with the blood to become spirits, thus maintaining the quality and supply of arterial or "spirituous" blood. According to Colombo, the refinement and admixture of blood and air takes place in the lung itself; and the blood, thus almost completely changed, is conveyed in that condition by the arteria venosa to the left ventricle. He believes, however, that a small part of the refining operation is still left for the heart to do; and that the formation of the vital spirits is not quite complete until it has received this "last touch" from the left ventricle. Why he should suppose that anything of this sort remained to be done, after the action of the lungs, does not appear; but it was probably due to the persistent influence of a familiar idea, namely, the existence in the heart of important powers of coction or elaboration, of which he could not fully divest himself. At all events, his theory with regard to the mechanical course of the blood was complete. It was blood supplied to the lung from the right side of the heart by the vena arteriosa (pulmonary artery), which, after being mixed with air in the lung, returned to the heart on the left side by the arteria venosa (pulmonary vein).

But it is interesting to know how Colombo reached his conclusion, and for what reasons he was induced to make this change in the doctrine of the vascular system, the most important since the time of Galen. These reasons were three in number.

In the first place, he adduces the great size of the lungs, and the necessity, in order to provide for and maintain the vitality of such organs, that they should be supplied with spirituous, arterial, or "vital" blood, as he calls it, as distinguished from the non-spirituous, venous, or "natural" blood, which is only for the purpose of material nutrition. All other organs are supplied with arterial blood by branches from the aorta. But the lungs do not receive from this vessel any branch whatever, "large or small;" and how can spirituous or vital blood be conveyed to them either by the vena arterialis or the arteria venalis, neither of which pulsate? Consequently the arteria venalis must be for bringing the blood, already elaborated, from the lung to the heart; not for carrying it out of the heart to the lung (64).

It is evident that this reasoning is based partly upon an error, namely; that there are no arterial branches from the aorta to the lungs. The *bronchial arteries* were unknown to both Vesalius and Colombo, and were first described by Ruysch * a little over one hundred years later. But even admitting the absence of the bronchial arteries, it is not quite clear why that should have appeared so decisive to Colombo. For according to Galen and his followers, the arteria venalis supplied the lungs with spirituous blood in ample abundance for their vivification; the elaborated air having become vital spirits by virtue of the transforming agency of the left ventricle, an agency partly acknowledged by Colombo himself.

Secondly, in Colombo's opinion, the arterializing

* Delucidatio valvularum in vasis lymphaticis et lacteis. Accesserunt quædam Observationes anatomicæ rariores. Hagæ Comitis, 1665. Amsterdam edition, 1720, p. 19.

action of the lungs is shown by another circumstance namely, that the blood in these organs is already arterial; that is, thin, florid, and bright-colored, since clinical experience had long taught physicians to recognize blood as coming from the lungs, not only because it was expelled by coughing, but also because it had the above-named qualities, similar to those of arterial blood (65). In regard to this reason, it must be observed that the facts mentioned by Colombo, as well known to medical men, were explained by Galen in another way: namely, that the openings between the arteria venalis and the bronchial tubes were naturally of such size as to admit the passage of air into the artery, but not the exit of its blood into the bronchial tubes; and that it was only when these openings became unduly enlarged that a discharge of blood, necessarily arterial, took place from the lungs. It is evident that the same thing would occur, whether the arterial blood were formed in the lungs, or were produced in the left ventricle of the heart and thence supplied to the lungs by the arteria venalis.

But, finally, what seems to have impressed Colombo more than anything else was drawn from his observations and experiments on animals; in which he always found the arteria venalis containing no air, but full of arterial blood and yet not pulsating. As the arterial pulsation is an act having its origin in the heart, whence the vital spirits are disseminated, if the arteria venalis does not pulsate, it is because the blood in this vessel is going to the heart, not coming from it. Colombo thought very highly of experiments on the living body and inspection of the organs in actual operation. In his chapter on this subject he declares that whoever will study in this way the motions of the heart, "can learn more in a little while about the variations of the pulse than he could in many months from external examination of the arteries;" and that he "could hardly gain, either as much pleasure or as much knowledge, from three months' study of *Galen De Pulsibus*, as in one short hour from the inspection of the heart in a living animal." He appeals to this evidence in support of his doctrine on the pulmonary circulation. He "advises, begs, and urges" his reader, whom he takes for granted to be an "earnest student of learned authors, but still more earnest for the truth," to make his observations on animals, and see whether what Colombo tells him is not borne out by the appearances; whether he do not find the arteria venalis full of spirituous blood, without any air, or "so-called fuliginous vapors," and also without pulsation (66).

This appears to be really the most important consideration in support of Colombo's doctrine. The pulsating action of the arteries was acknowledged to proceed from the heart, and to accompany everywhere the dissemination of the vital spirits throughout the body. If the arteria venalis alone, of all these vessels, did not pulsate, this must indicate some essential difference in its mode of action; the most natural explanation being that in this artery the blood is coming to the heart, not being carried away from it. Such an explanation was corroborated by the backward closure of the mitral valves, which, Colombo maintained, was not partial, but complete. For all these reasons combined, he was persuaded of the circuitous course of the blood from the right side of the heart, through the lungs, to the left ventricle.

Notwithstanding the extreme importance of this doctrine, and its great advance on all previous ideas, it still did not precisely represent the pulmonary circulation as now understood. Colombo by no means regarded the entire mass of blood, carried to the lungs by the pulmonary artery, as pouring through these organs and returning, in a continuous stream, through the pulmonary vein to the left ventricle. With him, as with former anatomists, it was a part only of the blood from the right side of the heart, which was destined to be mingled with the air of respiration, and thus become spirituous or arterial; the remainder of that contained in the pulmonary artery being used for the nutrition of the lungs, as the venous blood in general was for the nutrition of other bodily organs. His merit consisted in showing that that portion of the blood which was to replenish the arterial system passed from the right side to the left through the lungs; and, furthermore, that its arterialization took place in these organs, and not in the left ventricle.

But how was Colombo's doctrine received, and what influence did it exert on the progress of medical opinion? An examination of medical literature, for the remainder of the sixteenth century and the early part of the seventeenth, shows that it was considered, during that time, rather as an uncertain hypothesis than a demonstrated fact. It marks an historical epoch, but it did not make a revolution. Although for Colombo its truth was established beyond a doubt, it did not seem so clear to his contemporaries and followers; and the reasons which he found sufficient for his own belief were by no means convincing to others. Some adopted his conclusions wholly or in part; others held them in suspense; and by many they were denied or disregarded.

Ambrose Paré, in 1561, in his *Anatomie Universelle du Corps Humain*,* cites Colombo as having discovered (inventé) a new route for the blood from the right ventricle to the left, namely, that through the lungs and the arteria venosa, and speaks of this opinion as a "very probable" one.

Caesalpinus, in his *Peripatetic Questions*,† published in 1569, says that the lungs "are supplied with blood from the right ventricle by the vena arterialis, and transfer it by anastomosis through the arteria venalis to the left ventricle." According to him, however, the bronchial tubes, which are filled with cool air from without, "do not communicate with the arteria venalis, but run alongside its branches, and so temper its blood by their contact alone."

Felix Plater, Professor of Practical Medicine in the University of Basle, and author of a work on anatomy in 1583,‡ maintains that the "spirituous blood is formed by the mutual admixture of air and venous blood in the lungs;" and that, "when the heart contracts, the thick blood of the veins is poured out into the lungs; and when it dilates it draws into it the spirituous blood already formed in the lungs."

Bauhinus, Professor of Practical Medicine at the

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* Œuvres complètes d'Ambroise Paré, Paris, 1840. Anatomie Universelle du Corps Humain, livre ii., chap. xiv.

† Quæstionum Peripateticarum, lib. v., quæst. iv.

‡ Felicius Platerus, De Corporis Humani Structura, Basileæ, MDLXXXIII., p. 172.

university of Basle in 1605, in his treatise on anatomy,* presents Galen's doctrine of the transit of blood through the porous septum of the ventricles; but says that "some deny this transit, making the blood pass by the vena arteriosa into the lungs, where a part of it is used for nutrition; while the rest, altered and mixed with air, is carried by the arteria venosa to the left ventricle, for the generation and supply of the vital spirits and blood." "This opinion," he adds, probably in allusion to Plater, "was some time ago received with favor. But for our part we leave these matters to the philosophers (philosophantibus), as our object is to describe the real structure and use of the parts, so far as, with God's help, we are able to do it."

On the other hand, Falloppius, who was, like Colombo, a professor in the university of Padua, and whose complete works† were first collected and published in 1584, makes no mention of the pulmonary circulation. He says that the "elaboration of the vital spirits takes place in the left ventricle of the heart;" that the "vena arteriosa supplies the lungs with a finer quality of blood, corresponding with their finer and aëreal texture;" the arteria venosa, "carrying fuliginous matter from the left ventricle to the lungs, and bringing air, already prepared in the lungs, to the heart for its refrigeration." The blood of the right

* Caspari Bauhini Basileensis Theatrum Anatomicum. Francofurti, 1605, pp. 421, 422.

† Gabrielis Falloppii Mutinensis, Physici ac Chirurgici præclarissimi, in felicissimo Gymnasio Patavino olim rem Anatomicam et Chirurgicam admirabili cum laude publice profitentis, omnia quæ adhuc extant opera nunc primum tali ordine excusa, Venetiis, MDLXXXIIII., pp. 275–278. Institutiones Anatomicæ, Cap. De Thoracis.

ventricle "is partly for generating afterward vital spirits in the left ventricle, and partly for the nourishment of the lungs, to which it is sent by the vena arterialis." The reason why the lungs require so much blood for their nourishment is "on account of their continual movement, to supply the continual loss of substance thus expended." Although Falloppius admits that the spirituous blood is formed in the left ventricle, he says nothing about the interventricular septum, nor does he suggest in what way the blood reaches the left ventricle from the right.

Louis Duret, who was physician in chief to Charles X. and Henry III., and professor in the College of France from 1568 to 1586, wrote a commentary on Hollerius, *De Morbis internis*, which was first published the year after his death, in 1587. In this work* he says that "the dilatation of the heart draws air into the left ventricle and blood from the vena cava into the right, whence it is carried into the left by a passage which is inconspicuous and difficult to find in the dead body." By the heart's contraction, on the other hand, fuliginous matter is expelled through the arteria venosa; the thicker kind of blood through the vena arteriosa to the lungs; and the finer kind through the aorta to the body at large.

Andreas Laurentius, physician in chief to Henry IV. of France, and chancellor of the university of Montpellier, in his treatise on Anatomy† in the year

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* Iacobi Hollerii Stempani Opera omnia practica. Deinde Lud. Dureti, M. Regii ac Professoris in eundem enarrationibus, etc., etc., 1623. In caput xxix De cordis tremore seu palpitatione Dureti in suam enarrationem annotatio, p. 223.

† Andreæ Laurentii Historia anatomica humani corporis et singularum ejus partium. Parisiis, 1600. Lib. ix., cap. xi., pp. 482, 483.

1600, quotes Colombo's doctrine and the reasons in its favor, but rejects them as insufficient. The first of these reasons, namely, that the vena arteriosa carries more blood than is needed for the nutrition of the lungs, he says, has no weight; because the lungs, from their loose, spongy texture and their incessant motion, require an unusual quantity of nourishment to supply the waste. The second reason adduced by Colombo, namely, that the arteria venosa already contains spirituous blood, he says, is also invalid; since this vessel carries spirituous blood from the heart to the lungs, which need it, like other parts, for their vivification. In this connection he employs, on his own side, the same argument which Colombo used in an opposite sense; namely, that there are no branches going from the aorta to the lungs, to supply them with spirituous blood. "The more likely it seems," according to Laurentius, "and even indispensable, that the vital spirits should be distributed to these organs by the arteria venosa." Laurentius accordingly adheres to the doctrine of Galen and the transudation of blood through the septum of the ventricles.

Alpinus, Professor of Materia Medica in the university of Padua in 1601, in his book on Prognosis,* says that "the lungs in their dilatation receive from without cool air, which they communicate through the arteries (pulmonary veins) to the heart, to cool and moderate its fiery spirit, and in their contraction venti-

* Prosperi Alpini Maroticensis, Philosophi et Medici, in Gymnasio Patavino Medicamentorum simplicium Professoris ordinarii, De Præsagienda Vita et Morte Ægrotantium Libri septem, Venetiis MDCI., lib. iv., cap. i.

late the innate heat and purify the vital spirits by expelling from the heart its fuliginous vapors."

Fabricius, in 1615, in his work on the Organs of Respiration,* says that "the generation of heat and vital spirits is in the heart;" that the lungs are provided with the vena arterialis "for their own nutriment," while the arteria venalis "carries air from the lungs to the heart;" that the arteria venalis "is a passage for air, since, having the texture of a vein, it can take in air when it dilates, which would be impossible if it had the texture of an artery;" and that the vena arterialis "is a vein and contains blood, but has the texture of an artery to enable it to convey blood fine enough for the nutrition of the lungs." The meaning of the last phrase is, that if the vena arterialis had thin walls, like other veins, its blood, partly refined in the right ventricle, and consequently more attenuated than other venous blood, would escape from it and thus fail to reach the lungs; but that, having thick walls like an artery, it can retain this refined blood, as the arteries retain the still finer and more attenuated spirituous blood.

Finally Spigelius, in his Anatomy of the Human Body,† which was first published in 1625, embraces vigorously the doctrine of the passage of blood through the lungs from the right side of the heart to the left; but he says that, up to that time, "nearly all anatomical writers have maintained that the vena arteriosa

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* Hieronymi Fabricii Opera Omnia Anatomica et Physiologica. Lipsiæ, 1687, p. 161. De Respiratione et ejus Instrumentis, cap. iii., De Corde, & cap. xii., De Pulmonibus.

† Adriani Spigelii Bruxellensis Opera Omnia. Amsterdami, 1645, p. 139, 184. De Humani Corporis Fabrica, lib. v., cap. i., & lib. vi., cap. vi.

conveys nutriment to the lungs, while the arteria venosa carries air from the lungs to the heart." And although he accepts the doctrine of Colombo in so far as regards the course of the blood, he nevertheless emasculates it of a most important part; namely, the mixture of blood and air, and consequent arterialization of the blood in the lungs. For Spigelius still believes that the attenuation and elaboration of spirituous blood take place in the left ventricle; and he maintains, like Caesalpinus, that the air in the bronchial tubes only cools the blood by contact with the adjacent pulmonary vessels, and is not taken up by them or conveyed, in any form, to the heart. Of all the writers above mentioned, on one side or the other, Paré and Laurentius are the only ones who quote Colombo by name.

It is evident that there were difficulties in the way of the pulmonary circulation, not easily overlooked by the anatomists of the sixteenth century. Vesalius had shaken their faith in the perforations of the interventricular septum, but had not indicated any other route from the right side of the heart to the left. Beside the doctrine of Colombo there were no less than three other ways proposed, to account for the supply of blood to the arterial system.

I. Leonardo Botalli, in 1565, published a monograph on the *Vena arteriarum nutrix, a nullo antea notata*,* which was nothing less than a notice of certain cases of persistency, in adult life, of the foramen ovale, forming a communication between the right and left auricles. This foramen, as it exists in the fœtal heart, had already been described by Galen, as well as the normal

* Leonardi Botalli Opera Omnia. Lugd. Bat., 1660, p. 66. Observationes Anatomicæ. Observatio iii.

process of its obliteration after birth;* but Botalli imagined that he had discovered, in his exceptional cases, the "duct or vein which might be properly said to supply the arteries and the vital spirits, because through it, and not through either the septum or the arteria venosa, the blood finds its way into the left ventricle, and consequently into all the arteries." At the time of the publication of this discovery, Botalli was court physician to Charles IX., of France; and notwithstanding it was afterward recognized as a mistake, his name remained attached to the foramen, which is still sometimes designated by French writers as the "trou de Botal."

II. Varolius, in his work on Anatomy,† first published in 1573, does not believe that the blood of the left ventricle has ever come, by any passage whatever, from the right side of the heart. He observes that in the fœtus there is one umbilical vein, bringing venous blood from the mother to the liver and vena cava of the fœtus; and two umbilical arteries, bringing arterial blood from the mother and opening into the abdominal aorta of the fœtus. He concludes that in the adult there is a similar condition; namely, that the portal vein absorbs from the intestine the materials appropriate for venous blood, while the mesenteric arteries absorb what is required for the generation of arterial blood, and transmit it to the abdominal aorta. According to him, therefore, "the material needed for this generation is taken up from the intestines and delivered

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* Galen, Opera Omnia, vol. iv., pp. 243–245.

† Constantii Varolii, Philosophi ac Medici Bononiensis, Anatomiæ, siue De Resolutione Corporis Humani Libri iiii. Francofurti, 1591. Lib. ii., cap. i., p. 54, & lib. iii., cap. iv., p. 72.

directly through the arteries to the heart." In this way he avoids the difficulty of supposing a transit of blood from the right ventricle to the left, when there are no passages for such a transit, "unless we imagine some which are imperceptible to the senses."

III. Thirdly, Umeau* fixed upon the *spleen* as the organ in which a portion of the venous blood, freighted with the juices of digestion and freed from its biliary dregs, was transferred to the arteries and so conveyed to the heart, to be mingled with air in the left ventricle for the generation of the vital spirits. But these physiological ventures do not seem to have met with success; and there is little evidence that either of them received any other support than that of its author.

Among the obstacles encountered by the doctrine of Colombo was, no doubt, the familiar idea of the arteria venosa (pulmonary vein) as a vessel containing air rather than blood; and this idea frequently recurs, notwithstanding Colombo's assertion that in vivisections the vessel in question is always full of blood. Galen taught that the arterial blood was vaporous and spirituous in quality, but that neither air, vapor, spirits, nor anything else of the kind, were perceptible in it under their own form.† According to him, these gaseous and spirituous substances were incorporated with the blood of the arteries, or, as we should say, in solution; and he makes no exception to this in the case of the arteria venosa. His references to the matter are too numerous‡ to admit of a doubt, that in

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* Franciscus Ulmus, De Liene, Parisiis, 1578. Haller, Bibliotheca Anatomica, Lugd. Bat., 1774, tom. i., p. 247.

† Galen, Opera Omnia, vol. iv., p. 707.

‡ Galen, Opera Omnia, vol. ii., p. 597; vol. iii., pp. 451, 452, 539, 541, 544.

his doctrine, as against Erasistratus, this vessel contained spirituous blood, and not spirits alone, or any aëriform substance. But this seems to have been overlooked or misapprehended by writers of the middle ages; and because Galen sometimes speaks of the heart "drawing air from the lungs by the arteries of these organs, as plants by their roots draw nutriment from the soil,"* they imagined the pulmonary vessels to be filled with air in bulk, coming from the lung to the left ventricle.

Another misconception was that in regard to the pulsation of the pulmonary vein. In the doctrine of Erasistratus this vessel, the arteria venosa, pulsated like other arteries, and for the same reason. But Galen, who devotes nearly a chapter to this subject, is careful to say that such pulsation cannot be detected in it in vivisections,† and he prefers to distinguish the vessels of the lung as arteries or veins, only as they contain arterial or venous blood. Subsequently, the pulsation of the arteria venosa seems to have been taken for granted simply because it was an artery, although Colombo's experiments had shown that this was not true; and in the *Institutiones Anatomicæ* of Caspar Bartholinus, first published in 1611, the definition of this vessel was concisely given as follows: "It is called an artery from its function; for, first, it pulsates, since it is continuous with the left ventricle; and, secondly, it contains and carries air" (67). These discrepancies show the uncertainty which existed, both as to the truth of Colombo's opinion, and the grounds on which it was based.

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* Galen, Opera Omnia, vol. v., p. 525.

† Galen, Opera Omnia, vol. v., pp. 596, 600.

Among the earliest to admit the doctrine of the transit of blood through the lungs was ANDREAS CAESALPINUS. He was for a long time professor of Philosophy and Medicine in the university of Pisa, where he was also director of the Botanical Garden. While a resident of that city, he is supposed to have followed the anatomical lectures of Colombo, from 1546 to 1548. Afterward he was called to Rome, where he passed the remainder of his life as physician in chief to Pope Clement VIII., and as professor of Medicine in the Sapienza college. His works were on a variety of subjects, namely, philosophy (Quæstiones Peripateticæ, 1569), dæmonology (Dæmonum Investigatio Peripatetica, 1580), botany (De Plantis, 1583), Materia Medica (De Medicamentorum Facultatibus, 1593), mineralogy (De Metallicis, 1596), and general medicine (Quæstiones Medicæ, 1593; Speculum Artis Medicæ Hippocraticum, 1601; Praxis Universa Artis Medicæ, 1606). The last of these works was posthumous, as its author died in 1603. His reputation was first established as a writer on philosophy; although he was afterward distinguished for his works on botany, in which he first introduced a classification of plants founded on the organs of fructification. His position in Rome as professor and medical adviser to the Pope shows the estimate in which he was held as a physician; and his Speculum Hippocraticum was republished soon after his death in Germany, as a desirable epitome of the medical art.

Caesalpinus represents very well the excessive erudition which was more or less in vogue at the time when he wrote. His book of "Peripatetic Questions" is not easy reading. Its topics are so profound, and their treatment so extensive, that the perseverance of the reader is soon exhausted, and he willingly accepts the advice of Chereau, in the *Dictionnaire Encyclopédique des Sciences Médicales*, to resort for further information to the comments of some philosophical expert. All critics agree that Caesalpinus was devotedly attached to the philosophy of Aristotle, whose opinions and methods he advocated with an almost "religious zeal." This was the case even in regard to anatomical and physiological matters, a number of which are introduced in the fifth book of his "Peripatetic Questions." In one of these he discusses the spontaneous generation of animal bodies, even of man himself, from putrefying material; in another, the different parts taken by the male and female elements in the formation of the fœtus; in another, the supreme importance of the heart as the origin, not only of the arteries, but also of the veins and the nerves; and in another, the residence of the vital principle, not in the separate parts of the body, but in the heart alone. In this book he also presents his view of the course of the blood from the right ventricle through the lungs to the left, during which passage it is cooled by the contact of the bronchial tubes containing air. "The lung accordingly," he says, "drawing warm blood, by the vena arterialis, from the right ventricle of the heart, and transmitting it, by anastomosis, to the arteria venalis which goes to the left ventricle, tempers it, by contact alone, by means of the cold air transmitted in the meantime through the bronchial tubes which run alongside the arteria venalis, but do not, as Galen thought, communicate with it by inosculations" (68).

He still, however, believes that the transit of blood through the lungs is only partial; as a portion of it transudes through the interventricular septum, according to the doctrine of Galen. "All the parts therefore," he says, "are admirably constructed. For since the blood needs to be warmed in the heart, in order that its nutritive material may be brought to perfection; first in the right ventricle, where the blood is still of a thicker consistency, then in the left, where it is already more refined; it is transmitted, partly through the median septum, partly through the lungs for the purpose of refrigeration, from the right ventricle to the left" (69).

But the chief interest connected with Caesalpinus lies in his having been credited by some writers with a knowledge of the general circulation (70). De Renzi endeavors to establish this, in part, by a somewhat elaborate collation and explanation of quotations from the Quæstiones Peripateticæ and the Quæstiones Medicæ; but it depends mainly on a single sentence in the botanical treatise, entitled De Plantis. In this work the author begins by treating of vegetable physiology in general; that is, the organic character of plants as distinguished from animals, their mode of nutrition, germination, fructification, reproduction, and morphology. This occupies the whole of the first book. The main distinction between the animal and vegetable kingdoms, according to Caesalpinus, is, that while plants are endowed only with that kind of vitality (anima) which provides for nutrition, growth, and reproduction, animals have, in addition, the faculties of sense and motion. They require, accordingly, a finer kind of nutriment, over and above what is needed for vegetative life, and a more multiplied preparation and coction; so that, although both plants and animals have "veins," or their analogues, for the absorption and distribution of aliment, these vessels are differently arranged in the two classes. This is the occasion of his well known reference to the vascular apparatus, in this book.

The passage in question is as follows: "We will now consider how the attraction of aliment and the process of nutrition take place in plants; for in animals we see the aliment brought through the veins to the heart, as to a laboratory of innate heat, and, after receiving there its final perfection, distributed through the arteries to the body at large, by the agency of the spirits produced from this same aliment in the heart" (71).

To all conversant with the history of physiological doctrine, it must be evident that there is nothing in this passage which would imply in Caesalpinus a knowledge of the general circulation. It was not taken in that sense by his contemporaries, nor was such an idea alluded to by any other writer of the sixteenth century. There was no reason why it should be; for it is not presented by Caesalpinus as anything new, but only to illustrate the different modes of nutrition in animals and in plants. It expressed the accepted doctrine, namely, that the aliment, first produced as chyle in the stomach, and brought to the liver by the portal vein for sanguification, is thence taken through the hepatic veins and vena cava to the heart, where its "ultimate perfection" is given to it by the formation of the vital spirits, under the stimulus of which it is distributed by the arteries throughout the body. The same language might have been used by Galen or any subsequent writer, without attracting attention as anything novel. To suppose that Caesalpinus meant to describe an inward current toward the heart through the veins in general, as contrasted with an outward current through the arteries, would be an unnecessary and forced construction of a very simple statement; namely, that of the delivery of nutritious blood from the liver through the vena cava to the right ventricle of the heart, to be used for the production of spirituous blood in the left ventricle. The great mass of venous blood was believed by Caesalpinus, as by everyone else, to be distributed over the body, through the vena cava and its branches, for the nourishment of the parts. His only peculiarity in this respect was that he recognized, in accordance with Aristotle, two kinds of aliment in the blood; one an "alimentum auctivum," which provided for the increase of substance in the parts; the other, an "alimentum nutritivum," which replenished their specific qualities.* The first of these resided in the blood of the vena cava, and was prepared by the coction of the stomach and the liver; the second was the more perfected aliment, produced in the heart and distributed by the arterial blood.

Should there be any doubt remaining on this point, it is easily removed by reference to other passages in the works of Caesalpinus. In the fifth book of the Peripatetic Questions, the third chapter is devoted to establishing the doctrine, in conformity with Aristotle, that the heart is *the origin, not only of the arteries, but also of the veins and the nerves.* In the course of this chapter he says: "But if the heart be the origin of the blood, it must also be the origin of the arteries and

* Quæstiones Peripateticæ, lib. v., quæst. iii., p. 117, E, F.

the veins; for these are vessels intended for the blood. As, therefore, rivulets derive their water from a fountain, so do the veins and the arteries from the heart" (72).

"For they both (vena cava and aorta) flow from the same origin, the heart; because a single origin is better than several, and also for the other reasons adduced above; from the hot and capacious right ventricle, containing a thicker blood in which the heat is more intense, goes the vena cava; while from the other and smaller ventricle, containing a tempered and purified blood, passes out the aorta on the left side" (73).

In speaking of the supply of blood to the brain he says: "From the heart pass out the veins and the arteries, of which those which go to the head, after entering the calvaria, partly make up the retiform plexus in the ventricles, and partly constitute certain common sinuses in the dura mater, from which are distributed the bloodvessels to the pia mater" (74).

Finally, in his Speculum Artis Medicæ, the last work published during his life, he says: "The vena cava supplies a material from the liver, which Aristotle calls the *alimentum auctivum.* The aorta receives a perfected aliment, called the *alimentum nutritivum*, because it provides for consumption" (75). And farther on, in the section on the organs of the abdomen: "There are two great veins, giving off numerous branches, the vena porta and the vena cava, which have their roots, as it were, in the liver. From the portal vein many branches extend to the stomach and intestines, passing in company with the arteries through the mesentery, whence they are called mesaraic veins, absorbing the chyle, in order to carry it to the liver, converting it meanwhile into blood. . . . . . The vena cava, on the other hand, distributes its branches through the whole body, in order that, simultaneously with the arteries, they may nourish all its parts" (76).

If we recall what is said by Caesalpinus on the passage of blood through the lungs, it is plain that, so far from being acquainted with the circulation of blood through the body in general, he did not even accept the pulmonary circulation in the full sense given to it by Colombo; since he acknowledged a partial transudation through the interventricular septum, and regarded the air in the lungs as having only a cooling, not an arterializing, action on the blood. His main purpose is to defend the physiological ideas of Aristotle as against Galen, rather than to carry the doctrine of either to a further development.

The discovery of the valves of the veins we owe to Hieronymus Fabricius, called, from the place of his birth, Fabricius ab Aquapendente. It is true that valves had been already seen, in a number of veins, by various observers; among whom were Etienne, Cannani, Amatus Lusitanus, Sylvius, and Alberti. But they seem to have been regarded as local or exceptional formations, and were doubted or denied by anatomists of such reputation as Falloppius* and Eustachius.† Fabricius demonstrated their existence as a general feature of the venous system, and de-

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* Observationes de Venis. Observatio Quarta. Opera omnia, 1584, p. 332.

† Opuscula anatomica. De Vena sine pari. Antigramma xi.

scribed them in such a way that there was no longer any uncertainty as to their reality or importance.

Fabricius was educated at the university of Padua, where he was the pupil of Falloppius; and his industry and talent were so soon recognized, that at the age of twenty-five years he was chosen to conduct the anatomical demonstrations in place of his deceased master. He afterward became Professor of Anatomy in the same university, and discharged the duties of this chair for a period of thirty years. He reached an advanced age, and is said to have been engaged for nearly fifty years in the work of medical teaching. He was also successful as a practical surgeon; and appears to have been highly esteemed for his personal qualities, especially for his disinterestedness and liberality in professional matters.

His observations on the valves of the venous system were first made in 1574. They were subsequently continued and amplified, and made the subject of demonstration in his public lectures; and in 1603 they were embodied in a special treatise,* amply illustrated with large and well-executed engravings.

Fabricius tells us how he discovered the venous valves, "to his great delight," while engaged in dissecting. He calls them "little doors" (ostiola), or "delicate membranes" within the veins, opening upward toward the root of the veins, that is, toward the heart, but closing downward, that is, toward their ramifications. He thinks former anatomists in some measure excusable for having overlooked so extraordinary a formation. "For who could have expected

* Hieronymi Fabricii ab Aquapendente, Anatomici Patavini, De Venarum Ostiolis. Patavii, 1603.

such membranes to be found within the veins? Especially as we should anticipate that these vessels, intended to convey blood throughout the body, would have their cavities free, for the free passage of the blood." He describes faithfully the semilunar form and mode of attachment of the valves; their arrangement singly or in pairs; their alternate position in the same vein, like the successive branches of a plant; their abundance in the veins of the limbs, and their absence from the trunk of the vena cava and the internal jugulars; and among his plates there are two of the crural vein turned inside out, showing the valves in that position.

The use of the valves, according to Fabricius, is as follows: In his opinion, they are "so constructed, in order that they may in some measure retard the blood and prevent its running pell-mell, like a river, into the feet, hands, or fingers, and being impacted there." If that were to happen there would be two difficulties: "First, the upper parts of the limb would suffer from a deficiency of aliment, and secondly, the hands and feet would be burdened by a constant tumefaction." But, owing to the form and action of the valves, this danger is avoided, and all parts of the limb are enabled to receive the blood in just quantity and proportion. That shows why the valves are numerous in the veins of the arms and legs, but infrequent or wanting in those of the great cavities of the body. "Because the brain, heart, lungs, liver, and kidneys, organs which serve to keep up the general vitality of the system, need an abundance of aliment (which, for them, should not be in the least retarded), both for replenishing their substance and for generating the vital and animal spirits."

Another advantage of the valves is that they strengthen the veins, and enable them to bear a pressure which might otherwise cause their dilatation ; and the resisting capacity of the valves, notwithstanding their delicate appearance, is duly noticed. "For in the case of varices, where the ostiola are either relaxed or ruptured, we always see the veins more or less dilated. From this we can no doubt conclude that the ostiola are also useful for preventing venous distension, because the veins, with their thin membranous walls, are especially liable to be distended and dilated."

Lastly, Fabricius notes that the locality and action of the valves may be made visible in the superficial veins by the swellings or sinuses above them when they are filled as in an arm prepared for venesection, which is very handsomely illustrated in one of his plates. "Furthermore," he says, "any one can make the demonstration, either in the exposed veins of the dead body, or by ligature of the limb in the living subject, as in the operation of bloodletting. For if you try to urge or force on the blood by stroking it downward, you will plainly see its course intercepted and retarded by the ostiola."

Fabricius, accordingly, discovered and described a most important element in the structure of the venous system, which to us seems like an unmistakable guide-post, to show the inward course of the blood through these vessels. In fact, it afterward became a valuable aid in the discovery of the circulation. But for the time being, notwithstanding its apparent significance, it remained barren of results ; and the veins were still believed, as implicitly as ever, to serve for the supply of blood from the central to the peripheral parts. This has often been regarded as a matter of surprise; and it is sometimes considered as almost inexplicable why an indication, which appears so positive at the present day, was not equally plain to Fabricius and his contemporaries.

But a still more striking instance makes it evident that the mechanical structure of a part is not always sufficient to show its mode of operation. The *cardiac* valves had already been known since the time of Erasistratus, that is, for eighteen hundred years; and yet these valves, all opening in one direction and closing in the opposite, never even suggested the idea of a circuitous course of the blood through the heart and lungs, until it was announced by Colombo. Even then the doctrine of the pulmonary circulation was by no means generally accepted, and did not find favor with Fabricius himself.

Secondly, both the cardiac and the venous valves were largely regarded as closing imperfectly, and as forming therefore only a partial, not a complete, obstacle to the passage of the blood. This is true in regard to many of the venous valves, and with some anatomists is still a matter of question as to the tricuspid valves of the heart. Fabricius especially mentions that even the double valves do not always obstruct the entire calibre of the vein, thus leaving a portion of it still free for the passage of blood.

But the principal reason why the anatomists of that day did not appreciate the full meaning of this discovery is to be found in their inadequate knowledge of the motion of the blood. According to them, the blood in the veins moved from within outward, to supply nourishment for the tissues; but it moved, of course, no faster than it was absorbed and consumed at the periphery. The flow of blood, as they understood it, was very different from that which is now familiar to the student of physiology. The idea of a continuous current, carrying all before it, and moving, under the heart's impulse, with a velocity of ten or fifteen inches per second, had no place in their conception of the vascular apparatus. To them it was rather like the slow swelling of the tide, in an inlet already nearly full. The valves, consequently, did not present so absolute an obstruction. Such a quiet stream might, no doubt, creep past these valves; though any forcible or unusual impetus would distend them and block the passage. That was why nature had made them especially abundant in the limbs, where the frequent exercise of muscular activity was a source of danger from excessive impulsion. Thus the valves were regarded, not very unreasonably, as a safeguard against congestion of the parts beyond, from temporary or accidental causes. Is not that exactly the function which we still attribute to them? The difference between our doctrine and theirs is, that with us the source of the possible congestion is the compression of the venous trunk, obstructing the flow of blood from the capillaries; with them it was the undue impulse of blood from the trunk of the vein toward its branches. At all events, it is certain that the knowledge of the venous valves did not change, in any essential particular, the accredited doctrine of the vascular system. Like many other improvements of similar character, it had its value as a necessary step in the development of anatomical and physiological science; but its significance was greatly enhanced when it came to be considered, at a later day, in the light of further discoveries.

At the close of the sixteenth century the study of anatomy and physiology was marked by great activity of independent research. From Vesalius to Fabricius there had been a succession of ambitious and enterprising investigators, each endeavoring, so far as in him lay, to enlarge the boundaries of medical knowledge, and to confirm or improve its ancient doctrines. The progress which had been made consisted chiefly in the addition of anatomical details, and the more correct description of structures already known. The physiological action of the heart and bloodvessels remained for the most part what it had been from the time of Galen. As generally understood, the heart was still the seat of vitality, the source of animal heat, the laboratory of vital spirits and arterial blood; and the two great systems of vessels, veins and arteries, both served for the supply of blood throughout the body. But in some particulars the vascular physiology of that day deserves a closer examination, in order to appreciate the changes afterward introduced.

One of the features in the doctrine of the sixteenth century which often seems obscure, is that it recognized two systems of bloodvessels, both carrying blood from the centre to the periphery, but none bringing it back. How could the anatomists of that time have supposed it possible that all this movement should be in the direction of expenditure, and none in that of return? Must not the tissues, under such a dispensation, be inevitably overwhelmed with the blood thrown upon them by two simultaneous currents, without any means of relief from its superabundance?

But this becomes more intelligible if we remember that in the physiology of the time the wants of *nutrition*, as we understand it, were supplied, mainly or altogether, by the venous blood. It was this blood, rich in the immediate products of digestion, which distributed to the tissues the substances required for their material growth and renovation. The arterial blood, on the other hand, supplied them with the stimulus of *vitality and heat*. It was the vehicle of the vital spirits, communicating to all parts the endowments of life; and a portion of the vital spirits, converted in the brain into animal spirits, provided through the nerves for the active manifestation of the senses and will. Thus the two kinds of blood were subservient, each in its own way, to the process of supply which we now attribute to arterial blood alone. This distinction is evident from many expressions used by the writers of the period, which show that, in their view, the venous blood served the organic system for its nutrition, the arterial blood for its vivification (77).

Furthermore, the ingredients of both venous and arterial blood, distributed from the centre of the sanguiferous system, were expended and consumed at its periphery. The source of daily supply for venous blood was the digested food, or chyle, absorbed from the intestines by the portal vein, and distributed by the vena cava and its branches throughout the body, where it was appropriated, in corresponding measure, by the tissues. Thus the exhaustion of the blood at the venous extremities kept pace with its renovation at their source. "As the stomach, when it has digested the food received by the œsophagus, and delivered it to the intestine lower down, soon calls for more food, so the liver, transmitting to the veins the chyle brought by the vena porta, and converting it into blood for the continual nourishment of the body, at once demands, as if famished, a fresh supply of chyle. In like manner each particle of the body takes blood from the little veins, not indeed to transmit it to other parts, but to retain it for its nourishment, and assimilate it to its own substance; and the blood, thus appropriated and assimilated, is soon after resolved into vaporous excretions and disappears. So all parts of the body require new aliment, as the stomach must have new food; the liver new chyle, or the milk-glands new blood."* Botallus estimates † that at least one pound (twelve ounces) of blood is produced and consumed daily by the healthy human body.

On the other hand, the arterial blood was expended still more rapidly; for its essential ingredient, the vital spirits, generated incessantly from the breath, was diffused throughout the system by the arterial pulsation, and dissipated in the production of heat and vitality; while that portion of it which, in the brain, became animal spirits, passed through the nerves to the organs of sense and motion. The supply of blood, therefore, both venous and arterial, was no more than required to maintain the normal structure and activity of the bodily frame.

Another point of interest for the student of physiological history relates to the kind of *movement*, believed to go on within the bloodvessels. That a movement of some sort was recognized is evident

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* Botallus. De Curatione per sanguinis missionem. Antverpiæ, 1583, cap. i., p. 17.

† Ibid., cap. xxxiii., p. 174.

from the frequent passages which represent the blood as "agitated," "carried," or "transmitted" from one place to another. But these terms would be liable to misconception if we supposed them to indicate a definite and continuous transportation, like that which we now know takes place in the bloodvessels. The anatomists of the sixteenth century did not believe in two streams of blood, arterial and venous, running continually outward, from the centre to the periphery. That was manifestly impossible; and what has already been said on the subject of nutrition, shows that their idea of the motion of the venous blood was quite unlike that of a current or stream.

The motion of the blood in the veins, as then understood, was, in the first place, independent of the heart's action. A portion of the venous blood was drawn into the right ventricle for further elaboration, or for transmission to the lungs; but its distribution to the body at large was effected by the action of the veins themselves and the tissues which they supplied. Nearly all anatomists, like Vesalius, described the venous walls as containing three sets of fibres, longitudinal, transverse, and oblique; serving respectively to expand the vessel and draw into it blood from the neighborhood, to contract it and partially expel the blood, and finally to hold and retain its contents, for the time being, at rest.

By the action of these different fibres, the blood was attracted or impelled in the required direction for the needs of the various organs. But their effect was local and momentary, like a gentle peristaltic movement, which might come and go at successive intervals.

The action of the veins is very distinctly explained by Laurentius,* who calls them "canals or aqueducts for containing, preserving, and distributing the blood." They are, first of all, "vessels, or receptacles," for they "hold the blood, as it were, in safe-keeping; and if withdrawn from them, it at once putrefies or coagulates." Furthermore, they serve for its distribution; and this is accomplished "by attraction from neighboring veins and transmission to others, by means of their longitudinal and circular fibres."

Consequently the tendency of the blood, at any particular point in the venous system, might be in one direction or the other at different times. But beside this, there was an "insensible attraction," somewhat like our elective affinity, or force of osmosis, by which different ingredients of the venous blood might pass at once in opposite directions through the same vein. A striking example of this is the passage of blood through the portal veins to the intestine for its nourishment, and the absorption and transfer of chyle from the intestine to the liver by the same vessels. Laurentius avers distinctly† that this double passage may take place in a single vein at the same time. According to nearly all writers, the arteria venosa brought air or spirituous blood from the lungs to the heart, and also conveyed fuliginous vapors from the heart to the lungs; a thing which Bartholinus ‡ regards as not extraordinary, "since it often happens that aliments are attracted and excretions discharged by the same route." It is evident, accordingly, that the great mass of the venous blood was considered as in a comparatively quiescent

* Historia anatomica humani corporis, 1600, lib. iv., cap. ii.

† Historia anatomica humani corporis, lib. iv., cap. vii., quæst. v.

‡ Institutiones anatomicæ, lib. ii., cap vii.

condition; its renovation and distribution taking place gradually and without noticeable physical disturbance.

With the arterial blood it was very different. This was charged with the vital spirits, a vaporous or gaseous ingredient, incessantly generated and disseminated, by its own expansive force and the pulsific action of the vessels, to the confines of the arterial system. The bright color, attenuation and mobility of arterial blood, as distinguished from that of the veins, are forcibly described by Spigelius. "In the first place," he says, "the blood of the veins is more fibrous; that is, it contains more fibres (coagulating material). Secondly, it is thicker; that of the arteries, on the contrary, being more attenuated, owing to its coction in the heart. And lastly, they are distinguished by their color: for one is dark, the other ruddy; one destitute of spirits, the other impregnated with them; the one at rest, the other agitated by perpetual and incessant motion" (78).

But this motion or agitation of the arterial blood was still, in some sense, local both in its production and operation. It is not easy to gain a precise idea of its nature as understood in the sixteenth century, but it appears certain that it depended mainly on the action of the arteries. The heart, it is true, at each ventricular contraction expelled spirituous blood into the aorta. But the arteries were themselves gifted with a pulsific force; and the most important manifestation of this force was the active expansion of the vessel, by which blood, spirits and fuliginous vapors were drawn into it from adjacent parts. By its contraction, on the other hand, the vaporous materials of the blood were discharged through the skin and superficial membranes, some of the liquid and solid ingredients being retained by the tissues. Thus the pulsating movement of the arterial blood, as a whole, was not so much a progress as an agitation. It resembled the boiling of a cauldron rather than the undulations of a river. That it could not have had a very different significance from this is shown by the fact that the arterial branches were regarded, in some cases, as agents of absorption as well as of supply. The terminal anastomosis between arteries and veins was more frequently described as allowing a passage of blood from the veins to the arteries than in the opposite direction (79); and the mesenteric arteries were declared by Varolius* and Eustachius (80) to perform the function of absorbing nutriment from the intestine in the same manner as the mesenteric veins. These doctrines, of course, exclude the idea of a continuous current of blood, in the modern sense of the term, even from the arteries.

Not the least remarkable among the doctrines of this period was that of the *fuliginous vapors* produced in the living body and discharged by expiration. These vapors are so often mentioned, and their existence so confidently admitted, that it almost seems to imply, in the writers of that day, an intuitive perception of the modern results of physiological chemistry; for how otherwise could they have imagined the excretions of the breath to be identical in their nature with the gaseous products of combustion?

This doctrine, however, may be accounted for without attributing to the anatomists of the sixteenth century any gift of prescience or anticipation of modern

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* De Resolutione Corporis Humani, lib. iii., cap. iv.

discovery; for it only expressed certain truths already in their possession. They knew nothing, it is true, of oxygen or carbonic acid But they knew that a supply of fresh air was equally necessary for the maintenance of life and the process of combustion; and that air which had once been employed for either purpose was unfit for further use. Its quality was changed, so that it could neither support respiration nor feed a flame. In this respect, the vapors discharged with the breath were like those exhaled from burning fuel; and in each case the contamination of the air was preceded or accompanied by the production of heat. By nearly all writers, therefore, the resemblance in the effects was referred to the operation of the same cause. Colombo,* indeed, ridicules the idea of these "fuliginous or smoky vapors," discharged from the heart through the arteria venosa, "as if from the burning of green firewood." But he seems to have misapprehended, in some measure, the physical qualities attributed to these excretions. They were not to be looked for as opaque, dusky fumes, like the smoke of imperfect combustion; but rather like the transparent and invisible gases from the mouth of a furnace chimney. As the internal heat was produced in the arterial blood, together with the generation of vital spirits, the resulting vapors were discharged, and found their way out of the body, mainly through the lungs.

Lastly, the idea of respiration, as useful by its *cooling* or *refrigerating* influence, may also find a plausible explanation. It sometimes appears self-contradictory; because both the purpose and the result of this cool-

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* De Re Anatomica, p. 178.

ing influence are supposed to be the generation or maintenance of the internal heat. But the notion of a moderate degree of cold being favorable, and too much warmth unfavorable, to igneous activity was as old as Aristotle; and although it is not clearly explained by any of the ancient writers, many allusions employed by those of the sixteenth century help to make it intelligible. They observed that in the process of respiration the air which enters the lungs is cool, but when returned by expiration it is warm. So that which feeds a furnace fire is fresh and cool at its entrance, but comes out hot and stifling; and if fire be allowed to burn in a confined space, the warmer the air becomes the less it is capable of sustaining combustion. Their knowledge of the constitution of the atmosphere was limited, of course, to its physical qualities; and among the most noticeable of these were its coolness and warmth. They were accordingly disposed to regard its coolness as a property which fed or stimulated in some way the internal fire; especially as it disappeared from air which was vitiated and warmed by combustion. This explains why some, like Falloppius and Fabricius, regarded the air as taken up in the lungs and conveyed to the heart, there to perform its work of rekindling the vital heat; while others, like Caesalpinus and Spigelius, believed it to accomplish the same result by cooling the blood in the pulmonary vessels. In either case the maintenance of vital activity required a constant renewal of the air in respiration, while its effete products were discharged with the expired breath.

CHAPTER VIII.

HARVEY.

Within the limits of our present chronology there are two periods of commanding interest in the history of the vascular system; that of Galen and that of Harvey. Separated from each other by an interval of nearly fifteen centuries, they overlook all the intermediate epochs, and mark, each for itself, the starting point of a new physiology. They gain, rather than lose, from the effect of remoteness, and their importance becomes more apparent with the lapse of time.

In the year 1616, William Harvey began to discharge the duties of lecturer on anatomy at the College of Physicians in London. He was then thirty-eight years of age, a member of the college, and physician to St. Bartholomew's Hospital. He had received his early education in the university of Cambridge; after which he became a student of medicine at the university of Padua, where he continued for four years, obtaining his medical degree in 1602. He was consequently a pupil of Fabricius, at that time professor in the university, and probably the most celebrated anatomist of Europe. After completing his medical education, Harvey returned to London and engaged in general practice; where his appointment in the College of Physicians, some years later, shows the position which he gained in the estimation of his colleagues.

Not long after entering upon his office as lecturer

Harvey began to present to the audience his new belief in regard to the "motion and use of the heart, and the circuit of the blood." He illustrated it by dissections and experiments; discussing with his hearers the doubts and objections which occurred to them, and appealing in their presence to the test of "ocular demonstration." This he did for the reason that his conclusions were so different from the accepted doctrine, and diverged so much "from the path followed for ages by men of learning and renown," that he felt it would be an arrogance to declare them in public, without first submitting them to the judgment of his colleagues. He continued to pursue this course for nine years,* at the end of which time, in 1628, he published his work,† already completed in manuscript several years before (81).

This volume, a small quarto of seventy-two pages, undoubtedly contains a greater amount of important material in small compass than any other medical work ever published. Its doctrines are presented with such clearness of statement, and in such regular sequence as to leave no uncertainty in regard to the convictions of the author or the manner in which he came to adopt them. Notwithstanding his confidence in the truth of his opinions, there is never in his language anything like assumption; for he relies throughout on the candor and intelligence of his reader, and

* Dedicatory Epistle to the President and Fellows of the College of Physicians.

† Exercitatio Anatomica de Motu Cordis et Sanguinis in animalibus, Guilielmi Harvei Angli, Medici Regii & Professoris Anatomiæ in Collegio Medicorum Londinensi. Francofurti, M.DC.XXVIII. There is a fine copy of this edition in the Astor Library, New York, presented in 1874 by Prof. Austin Flint, Jr., M.D.

on the reasonable evidence of observation and experiment. It is by this means that he reached his own conclusions, and he believes that the same proof will be sufficient for others.

The idea of a new departure in the physiology of the heart and bloodvessels seems to have taken origin, in Harvey's mind, from the discordances and incongruities which he found in the existing doctrine. With the majority, these imperfections passed unnoticed; or, if dimly perceived, were accepted as a necessity. But with him they were difficulties which needed explanation; and he could not rest satisfied with anything which implied a physiological contradiction, or which did not correspond with the testimony of the senses. These uncertainties are set forth by Harvey in his "Procœmium," or Introduction; where he enumerates the current opinions, which often seem "so inconsistent with each other that they are fairly open to suspicion." The first of these relates to the cardiac and arterial *pulsation*, usually regarded as an act similar to that of respiration: namely, a movement of expansion, in which the heart or bloodvessel attracts into its cavity material from the adjacent parts; so that the arteries "are filled, like bellows, because they are expanded, not distended like bags, because they are filled." But this doctrine, which had come down from Galen,* was not in accordance with the facts; for, as Harvey says, "when an artery is wounded the blood escapes in jets, now with greater, now with lesser impetus; and its more forcible expulsion is always at the diastole of the vessel, and not at its systole. This would not be so if

* Galen, Opera Omnia, vol. iii., p. 512; vol. iv., pp. 730–731; vol. v., pp. 163, 164; vol. xi., p. 598.

the diastole were a movement of expansion and attraction; for in that case it would draw air through the wound into the vessel, rather than expel the blood from it."

Secondly, there was an evident contradiction in the doctrine that the diastole of the heart and that of the arteries were simultaneous; for how was it possible, " if they work together in this way, that one should attract anything from the other, or that anything should be transmitted from one to the other?"

The assumption of porosities in the interventricular septum, for the passage of blood through it (82), was equally unsatisfactory; for, in the first place, "By Hercules, there are no such porosities, and they cannot be demonstrated." Beside, if there were any, "how could either ventricle draw anything from the other, since they both dilate at the same moment?" Furthermore, it seemed incredible and inconsistent that the thick blood should pass through these minute and imperceptible channels, while the air to be mixed with it had the widely open passage of the arteria venosa for its accommodation. This inconsistency was still more apparent from the fact that in the fœtus, " where the tissues are softer and more delicate," the foramen ovale was provided for communication between the right side of the heart and the left; and yet it was claimed that in the adult heart, " with all the density of age," transfusion could take place through the septum itself.

The transfer of air and blood, together or separately, to and from the heart, by the arteria venosa, was also a stumbling-block; for supposing the left ventricle to attract air and blood into itself for the generation of spirits, and to discharge spirituous blood into the aorta, thus expelling one way fuliginous vapors by the arteria venosa, and the other way spirits by the aorta, what caused their separation? And how was it that spirits and fuliginous vapors could pass this way and that without mixture or confusion? If the mitral valves did not obstruct the exit of fuliginous vapors toward the lung, how could they prevent the regurgitation of air in the same direction? It was said, furthermore, that, notwithstanding the mitral valves, the arteria venosa distributed to the lung spirituous blood. How could these valves prevent the passage of air, and not that of blood?

These were the difficulties, and others like them, which set Harvey's mind at work. Seeing so many things that were obscure or unreasonable in the teaching of his predecessors, he thought it would be well to consider the subject more closely, and he determined to study the action of the vascular system, "not only in man, but also in animals; and to prove and investigate the truth by frequent vivisections and repeated examination;" not to test his theory, for he had none, but to see whether he could find anything to remove the doubts and complications of the existing doctrine.

When we recall the state of physiological science immediately before Harvey's time everything seems ready for his discovery. Anatomy had been cultivated with ardor and success for nearly a century. The two kinds of blood, arterial and venous, were well known and fully distinguished by their physical qualities. The porosity of the interventricular septum was at least open to doubt, and the passage of blood through the lungs had been offered as a substitute by one of the best anatomists in Europe. Finally, the valves of the veins, opening toward the heart and closing toward the periphery, had been described and demonstrated to the satisfaction of all. They were there, to indicate plainly, one would think, to the first comer, that the movement of blood in the veins was from without inward, and not from within outward. This appears to us like the only thing wanting to establish the fact of the general circulation, and as the first with which a new investigator would almost certainly commence.

But what happened was exactly the contrary. Harvey began with the motion and uses of the heart, and its relation to the arteries. The course of the blood in the veins was the last fact at which he arrived, and followed as a final result upon his earlier investigations.

In his first chapter Harvey gives the reasons which induced him to write. They were as follows: When he first undertook to study the motion and uses of the heart by inspection of the living organ, he found great difficulty in understanding them. The movements were so confusing to the eye, by reason of their rapidity, that he could not even determine which was the systole and which the diastole; and he was almost ready to think, with Fracastorius, that the problem was too intricate for human comprehension. But at last, after many trials and much perseverance, he was enabled to solve the difficulty; and believed that he had succeeded in understanding the motion of both the heart and the arteries, and the work which they performed. Since then, he had freely presented the matter in his anatomical lectures, meeting with approval from some and dissent from others; and he was now led to publish it in printed form, "in order that all might share in the result of his labors," and "might form a judgment both of himself and his conclusions."

The second chapter is on *the character of the heart's motion, as shown by vivisections.* When the organ is exposed to view in a living animal, the first thing which strikes the observer is that it is alternately in motion and at rest; and that these two conditions follow each other in unceasing regularity. At the time of its motion three phenomena are noticeable:

"First. That the heart is erected, and raises itself up into an apex; so that at that time it can strike the chest, and a pulsation may be felt externally.

"Secondly. That it is contracted every way, but more so at the sides; so that it appears smaller, elongated, and drawn together.

"Thirdly. If taken in the hand, it perceptibly hardens at the time of its motion; this hardening being due to tension, like that felt in the sinews of the forearm, which grow tense and more resisting when they move the fingers."

In addition to the above, it can be seen in cold-blooded animals, as fish and reptiles, that the heart "at the time of its motion grows paler; but when at rest is deeply tinged with the color of blood" (83).

From these appearances Harvey draws the inference that the activity of the heart consists in a muscular tension and constriction of its fibres, producing induration and thickening of its walls and diminution of its cavities; and that, by this means and at this time, it expels the blood from its ventricles. This effect is especially indicated by the last-mentioned observation in cold-blooded animals, namely, that at the time of the heart's movement and erection it becomes pale from the absence of blood, while in its quiescence it resumes its deep red color. But this point is too important to be left for surmise; and Harvey's instinct carries him straight to the experimental test which shall settle it beyond dispute. "But no one," he says, "need have any further doubt about it; for if he make an opening into the cavity of the ventricle, he will see the blood escape forcibly at each successive tension or pulsation of the heart" (84). Consequently there are four occurrences simultaneous with each other; namely, the tension of the heart; the stroke of its apex, making an impulse externally; the thickening of its walls; and the forcible expulsion of blood, from constriction of its ventricles.

This chapter, the first in which Harvey's experiments are detailed, is not a long one, but it contains the substance of a volume. It opened the way for the whole discovery of the circulation; for it changed completely the idea entertained of the heart's movement, and reversed the significance of its sensible pulsation. The pulsation, striking against the walls of the chest, had been considered, very naturally, as due to the cardiac expansion or diastole; and this movement, the visible and palpable expression of the heart's activity, was credited with the power of drawing into it the liquids of the vascular system. Harvey demonstrated that the opposite of this was true; that the active movement of the heart was its systole, expelling the blood and coinciding with the external impulse; while its diastole was a passive condition, in which its fibres were relaxed. "Nor is there any truth," he says in conclusion, "in the common belief, that the heart by any spontaneous motion or dilatation attracts blood into the ventricles; for at the time of its movement and tension it expels the blood, and receives it at the time of its collapse or relaxation" (85).

The next chapter treats of *the character of the arterial motion, as shown by vivisections.* In this chapter, Harvey applies to the motion of the arteries the same inexorable test of observation which he had used for that of the heart. With the aid of the facts already established, he sees that at the moment of the heart's tension, constriction, and impulse, in a word, at its systole, the arteries are in diastole; and *vice versa*, the systole of the arteries corresponds with the diastole of the heart. The more languid the tension of the heart, the less perceptible is the arterial pulsation; and when the heart's action ceases altogether, the movement of the arteries also disappears. Furthermore, if an artery be divided or opened, the blood is driven out with impetus at the moment of the ventricular tension; and in the operation of arteriotomy, the forcible jet of blood is coincident with the arterial diastole and the heart's impulse at the chest.

Consequently there is a change to be made in the doctrine of the arteries, as well as in that of the heart. The arteries have no pulsific power, nor any force of expansion for attracting fluids into their cavity. They are filled and distended, at their diastole, "by the impulse and intrusion of the blood sent into them by the heart;" somewhat in the same way as when you blow into a glove, the fingers of the glove are distended by the force of the ingoing air. For this reason the arterial pulses follow exactly, in force, frequency, rhythm, and regularity, the tension of the heart; because they are dependent upon it for their existence. Anything which obstructs the movement of blood through the arteries, diminishes in the same ratio their diastole beyond the obstruction; "since the pulsation of the arteries is nothing else than the impulse of the blood within them."

Next to be considered is the motion of the *auricles*, and its relation to that of the heart. Anatomists in the seventeenth century still agreed in regarding the heart as properly consisting of the ventricles; the auricles being looked upon as appendages, either of the heart itself, or, more frequently, of the veins. This accounts for the phraseology in which the pulsation of the auricles is spoken of as one thing, and that of the "heart," or ventricles, as another.

Harvey observes that in the living heart there are four visible pulsations, or contractions, namely, two of the auricles and two of the ventricles. But although these pulsations are four in number, they are only two in time; for the auricles contract simultaneously with each other, and the ventricles also beat together; the auricular contraction preceding a little that of the ventricle. He gives an accurate account of the way in which these motions become successively enfeebled and disappear while the heart is dying; namely, that the left ventricle stops first, then the left auricle, then the right ventricle, and lastly, that the right auricle keeps up its action after all other parts of the organ are motionless.

These facts he does not offer as a novelty, for they were known before. He uses them to introduce an important observation, which can only be made while the right auricle continues to beat, though the other parts have lost their activity. "If at this time," he says, "you place your finger on the ventricle, while the auricle is still pulsating, you will perceive separate pulsations in the ventricle; in the same way as we have already shown the pulsation of the ventricles to be felt in the arteries, namely, from their distension by the impulse of the blood. And at the same time, the auricle alone pulsating, *if you cut off the point of the heart with a pair of scissors, you will see the blood escape from it with each auricular pulsation.* This shows, consequently, how it is that the blood gets into the ventricle; not by attraction or cardiac dilatation, but because it is impelled by the pulsation of the auricle."

The mechanism of the heart, therefore, is similar in all its parts. Its pulsation is everywhere a systole, or movement of contraction, expelling the blood from one cavity and introducing it into another. The only difference is in the strength of this contraction, which is very forcible in the left ventricle, less so in the right, and least of all in the auricles, whose walls are the thinnest. But the auricles also propel the blood, and they grow visibly paler in contraction, especially about their points and edges.

Having explained these essential preliminaries, Harvey goes on, in the fifth chapter, to describe fully *the motion, action, and function of the heart.* This is the way its motions take place. First the auricle contracts, propelling its blood into the ventricle; then the heart becomes erected, tightens its fibres, constricts the ventricles, and makes a pulse; by which the blood, introduced from the auricle, is discharged into the arteries; from the right ventricle into the vessel going to the lungs, and from the left ventricle into the aorta and its branches.

But these motions, although performed by different parts, are so connected with each other that there is no interval between them; and the whole cardiac pulsation forms a single continuous act. Every one who has watched the movements of the living heart will recognize the faithfulness of this description. Harvey compares it to the working of machinery, in which one wheel sets another in rotation, and yet all apparently move together; or, still better, to "the mechanism of a musket, where, at the touch of the trigger, the flint comes down, hits the steel and drives it forward, strikes fire into the powder, the ignition runs inward, there is an explosion, the bullet flies out and pierces the mark; and all these motions, from their quick succession, seem to happen at once, in the twinkling of an eye" (86). It is also like the movements of the tongue, fauces, pharynx, and œsophagus in swallowing. These movements are consecutive but continuous, and altogether they effect a single uninterrupted act of deglutition.

Here we arrive at the essential part of this chapter. The action of the heart, within the chest, is also a deglutition. It is a transport or transfusion of blood, from the veins to the arteries, by the successive parts of the cardiac apparatus. The similarity is such that Harvey cites it as an illustration. "When a horse drinks," he says, "and is swallowing water, we can perceive its transit through successive parts of the œsophagus, in its downward course to the stomach; for these motions make a sound, and cause a certain audible and tangible pulsation. So the transfer of blood, by the heart's motion, from the veins to the arteries, makes a pulse which can be heard within the chest."

The singularity of this illustration marks its importance. At the present day, to associate the cardiac circulation with the deglutition of water through the gullet of a horse, would seem a coarse and clumsy comparison. But as used by Harvey, it was the plain and forcible announcement of a physiological truth. It represented the heart for the first time as an organ of *propulsion for the blood;* that is, an apparatus of muscular cavities, transmitting it in successive undulations from one part of the vascular system to another. Before, it had been regarded as in some mysterious way the source of vitality and warmth, as an animated crucible for the concoction of blood and the generation of vital spirits. Harvey does not presume to say how far it may share in such endowments; but he declares that, so far as observation can show, it performs a work of physical transportation. "The motions of the heart, accordingly, are altogether after this fashion, and their single effect is the transfusion of the blood (from the veins to the arteries), and its propulsion through the arteries, to distant parts; the beat which we feel in the arteries being simply the impulse of the blood derived from the heart" (87).

But *by what route is the blood carried, from the vena cava to the arteries, or from the right ventricle of the heart to the left?* This is the title of the sixth chapter. The principal cause of difficulty on this point, according to Harvey, has been the mode of connection, in man and the higher animals, between the heart and the lungs. As the vena arteriosa from the right ventricle loses itself, apparently, in the pulmonary tissue, and the arteria venosa, on the left side, has a similar blind connection with the lung, anatomists were at a loss to see how the blood could pass that way, from the vena cava and right ventricle, to the left ventricle and the aorta. Nevertheless, that is the route which it follows; and this would not have appeared so improbable if anatomists had extended their dissection to animals of different classes, instead of confining it so much to the human cadaver.

Harvey shows, first, that in the animal kingdom for the most part, the passage of blood from the veins to the arteries, through the heart, is perfectly evident, and not open to doubt. This is the case in fishes, which have but one ventricle and no lungs; where the blood can be plainly seen entering the heart by the auricular appendage at its base, and expelled by the artery going to the gills, in the opposite direction. In frogs, serpents, and lizards, though they have lungs, these organs do not interfere with the transit of blood through the heart; and here also the way is manifest, with no more difficulty or doubt about it than there would be in man, if the septum of the ventricles were perforated or absent. Now, as the animals which do not have lungs are more numerous than those which have, and as there are more with only one ventricle than with two, it is fair to say that, "as a rule," in the animal kingdom, the blood passes from the veins to the arteries through the heart, by a plainly visible route.

But, in the second place, the same thing is true for all animals, and man himself, during fœtal life. The foramen ovale and ductus arteriosus are open channels, whereby the blood reaches the arterial system from the veins. At this time the lungs are inactive, motionless, and practically non-existent; and such a fœtus is in the condition of an adult animal where there never are any lungs (88). But after birth, when the lungs come into activity, these passages are closed, and there is no longer any way by which the blood can reach its destination except through the lungs. Harvey contends that it passes by this route; and he proposes to show, first, that such a transfer is possible, and next, that it actually takes place.

The following chapter is devoted to this point, namely, that *the blood transudes, through the pulmonary parenchyma, from the right ventricle of the heart into the arteria venosa and the left ventricle.* There is no impossibility in a transudation of this kind, for we constantly see rain-water filter through the earth, to reappear in springs and rivulets. Furthermore, perspiration passes in the same way through the skin, and urine through the kidneys. There is another physiological action, admitted by all, which is even more to the purpose. The entire product of digestion must pass, every day, through the liver, to reach the vena cava and replenish the blood. How can we accept this, as we must do, and deny that the blood can pass through the lungs? If the animal fluids transude through the dense and motionless substance of the liver and kidneys, they must be able to penetrate the spongy and movable tissue of the lung. Why, therefore, Harvey asks, should not his readers give the same credence to the passage of blood through the lung as to the permeability of the kidneys and the liver? and "why should they not admit the same thing, with Colombo, that most skillful and learned anatomist, from the size and structure of the pulmonary vessels, and the fact that the arteria venosa, as well as the left ventricle, is always filled with blood, which must have come from the veins, and by no other path than through the lungs; as both Colombo and myself believe to be plainly manifest, from what has gone before, from actual observation, and from other proofs beside" (89).

He holds it, therefore, to be undeniable that the blood passes continuously through the porosities of the lung, from the right ventricle to the left, and so from the vena cava to the aorta. Since it is going incessantly, from the right ventricle to the lungs and from the lungs to the left ventricle, as shown by the position of the valves, its continuous transudation must be admitted; and, in like manner, since it is constantly going into the right ventricle on one side, and as constantly coming out of the left ventricle on the other, it must necessarily be transmitted without interruption from the vena cava to the aorta.

Harvey now approaches, in his eighth and ninth chapters, a most important part of the subject; namely, that of the *amount of blood passing through the heart, from the veins to the arteries*. Heretofore he has occupied himself only with the fact that such a transfer takes place, and that it is effected through the lungs. But to an observer like him, the question of quantity could not long fail to present itself; and he sets himself at work to ascertain how much blood must pass the above route at each cardiac pulsation, and to how much this amounts in a given time. The results are most unexpected; and they carry him forward at once to a new stage of inquiry.

The left ventricle of the heart in a state of dilatation, that is, when it is full, may contain one ounce and a half, two ounces, or three ounces of blood. Harvey has found it to contain, after death, more than two ounces. Now the same ventricle in a state of contraction contains less blood than when it was full; and this difference represents, of course, what has been discharged into the aorta. It thus appears that at each contraction of the ventricle it expels one-quarter, one-fifth, one-sixth, or at the very least, one-eighth of its contents.

But the heart's pulsations are very frequent; and small quantities, continually added at short intervals, often accumulate to a surprising amount. So it is in this instance. In the human heart, at least one drachm of blood must be expelled at each contraction of the ventricle. With even the slowest pulse, there are, in the space of half an hour, more than one thousand pulsations. This represents one thousand drachms, or a little over ten pounds of blood, passing through the heart in half an hour, or twenty pounds per hour; that is, more blood than is contained in the whole body. If the estimate be extended over the entire day, it becomes evident that the quantity of blood thus passing through the heart and lungs, from the venous to the arterial side of the vascular system, is far greater than can be accounted for by the fluids already present, with the addition of those supplied by digestion. Such a superabundant transit would, in a short time, inevitably empty the veins and overwhelm the arteries with blood. There is only one condition in which it could be possible, that is, in case the blood *were to pass again from the arteries to the veins, and so return to the right side of the heart.* This would be, as it were, a "motion in a circle," in which the blood would be sent from the heart through the arteries to all parts of the body, and brought back by the veins to the vena cava and right auricle.

The rapid transit of blood through the arteries, in like proportion to the above, is made evident by demonstration. For if you open, in a living animal, the aorta, or even a small artery, the whole body will be emptied of blood in less than half an hour. Butchers know that they can drain the body of an ox, and make the whole of it exsanguine, within a quarter of an hour, by cutting off the arteries in the neck. It cannot be said that this blood is lost from the veins as much as from the arteries, for the same abundant hemorrhage comes from a divided artery when the vein has been left untouched; and in all cases the more active the arterial pulsation, the more rapid is the hemorrhage and the more quickly is the body drained of blood.

This is the way in which Harvey reached the idea of the circulation; first, by seeing that the pulsation of the heart is a muscular constriction, expelling the blood from its cavities; second, that the beat of the arteries is a dilatation, caused by the impulse of blood sent into and through them by the heart; third, that by the successive auricular and ventricular contractions the blood is transmitted, through the lungs and heart, from the veins to the arteries; and fourth, that this transmission takes place in such abundance and rapidity that it can only be kept up by the blood returning again to its starting point.

But in order to establish the reality of this circular motion, it must be shown to be continuous and complete in all its parts; namely, from the veins to the arteries through the lungs and heart, from the arteries to the veins in the distant organs, and lastly from these organs through the veins back to the heart; and everywhere in greater volume than can be explained by the quantity of blood or the daily supply of nutriment.

The first part of this circulation, from the veins to the arteries through the heart, has already been shown by computing the quantity of blood discharged from a wounded artery, and of that expelled, in the normal condition, at each ventricular pulsation. But in the tenth chapter it is corroborated by a further experiment, which gives decisive proof that the blood going out from the heart by the arteries has been supplied to it from the veins. If a living serpent be laid open, the heart can be seen pulsating regularly and quietly for a long time; growing pale in its systole and red in its diastole, and exhibiting distinctly all the appearances formerly described. " But this, in particular, can be shown clearer than daylight. The vena cava enters the heart at its inferior portion, while the artery passes out above. Now, if the vena cava be taken up with forceps or the thumb and finger, and the course of the blood intercepted for some distance below the heart, you will at once see it almost emptied between the fingers and the heart, the blood being exhausted by the heart's pulsation; the heart at the same time becoming much paler even in its dilatation, smaller in size owing to the deficiency of blood, and at length languid in pulsation, as if about to die. On the other hand, when you release the vein, the heart immediately regains its color and dimensions. After that, if you leave the vein free, and tie or compress the arteries at some distance from the heart, you will see, on the contrary, their included portion grow excessively turgid, the heart becoming distended beyond measure, assuming a dark red color, even to lividity, and at length so overloaded with blood as to seem in danger of suffocation; but when the obstruction is removed, it returns to its natural condition, in size, color and movement" (90).

The above experiment is well chosen. A serpent is especially useful for the purpose, owing to the peculiar elongated pattern on which its organs are constructed. The heart lies but a short distance below the neck; the superior vena cava being small, and much the greater part of the blood returning to the heart by the vena cava inferior. In a black water-snake (Tropidonotus sipedon) three feet long, the vena cava may be tied or compressed at a distance of two and a half inches below the heart; when the phenomena described by Harvey, namely, the emptying of the vein above the point of compression, the consequent exsanguine condition of the heart, and the quick return of blood from below on detaching the ligature, are all plainly visible. To one in Harvey's position, duly instructed in the common belief that the veins distribute their blood from within outward, this experiment must have been extremely impressive. It is especially convincing as to the rapidity with which the blood moves through the heart, from the venous to the arterial side of the circulation.

The next chapter is on the transit of blood *in the peripheral organs, from the arteries to the veins.* It is mainly taken up with the effect produced by various ligatures, and the difference between them. They are of two kinds; the "tight" ligature and the "moderate" ligature. The first is that by which a limb is so constricted that no pulsation can be felt in the parts below; such as those used to prevent hemorrhage in amputations, for the castration of cattle, or for the removal of tumors. The second, or moderate ligature, is one which embraces the limb completely, but without producing pain or suppressing arterial action below; like that used in venesection.

For Harvey's purpose they are employed as follows:

Let the arm be encircled above the elbow by a "tight" ligature, drawn as closely as possible without causing pain. It will then be observed that there is no pulsation below the ligature, either in the forearm, at the wrist, or in the hand; but just above it the artery has a wider diastole, and beats more forcibly than usual, as if to overcome an obstacle; the hand meanwhile retaining its size and color, only losing gradually a little of its warmth.

After the ligature has been kept for a time in this condition, let it be gently loosened, so as to become a "moderate" ligature, as in venesection. Instantly the hand grows flushed and distended, with its veins standing out tumid and tortuous; and after ten or twelve pulsations of the artery the parts are filled to repletion with the blood impelled and crowded into them. While the ligature is being loosened, a finger, placed upon the artery just below, will feel the blood gliding along beneath its touch; and the person subjected to the experiment perceives distinctly the ingress of warmth and blood into the limb, when the obstruction is removed.

From this it is plain that the blood enters the limb by the artery and leaves it by the veins. For while the artery is compressed there is no influx, nor discoloration, nor distension; but as soon as it is released, the blood penetrates with force and causes tumefaction. None of it comes in through the veins, for they are compressed; and the proof of this is that they are more swollen below the ligature than elsewhere, and that, so long as the ligature remains, they cannot be emptied by pressure into the parts above. On the other hand, the moment the ligature is removed the swollen veins collapse, unloading themselves toward the heart; and the redness, turgidity and congestion at once disappear.

While treating of these effects produced by the "moderate ligature," Harvey takes pains to show that the distension visible in the part is not due to "pain, heat, or any force of a vacuum." The ordinary effect of this ligature was, of course, well known to physicians; but it was generally attributed to a sort of "attraction" exerted upon the fluids, drawing them into the affected part. It was thought to be analogous to the heat, redness, pain and swelling of local inflammation; and seems to have been explained somewhat on the principle of *ubi irritatio, ibi fluxus*. But Harvey points out that the swelling, in case of such a ligature, is without either pain or irritation; and that there is none of it above the ligature, though it may occupy the whole of the limb below. In place of the obscure hypothesis of attraction, he offers the simple and intelligible explanation of the free entrance of blood by the arteries and its obstructed exit by the veins.

But how large is the *quantity* of blood passing in this way, at the periphery, from the arteries to the veins? This can be shown by opening one of the superficial veins in an arm prepared for venesection by the moderate ligature. In a short time the whole of the blood previously contained in the arm will be evacuated; and after that, the blood which continues to flow comes from the arteries of the internal parts. The impetus of its discharge is from the heart; for it has already been shown that the heart's action is the only force by which the blood is propelled. If the hemorrhage go on, the blood expelled at last from the wounded orifice must have come from the heart, and through the heart from the vena cava. It cannot descend from the veins above the ligature, for they are impervious; and if the bleeding be kept up for half an hour, most of the blood will have come from the great veins, through the heart to the arteries, and so through the vessels of the arm to the opened vein. Now, if we estimate how much blood can be drawn, in this way, from the cephalic or basilic vein, within the space of twenty or thirty pulsations; how much passes during the same time through the arm of the opposite side; how much through the thighs and legs, the head and neck, and all the other vascular organs; it will be evident that this quantity is greater than the whole mass of the blood, and vastly more than can be derived from the daily aliment, or consumed in the nutrition of the parts. It must be supplied from the centre of the circulation; that is, from the blood discharged by the left ventricle, which has come, through the lungs and heart, from the vena cava.

Lastly, Harvey arrives at his third division of the subject; namely, the return of the blood, *through the* *veins, from the periphery to the heart.* He begins this chapter with a description of the venous valves, the discovery of his former master, the "clarissimus Hieronymus Fabricius, peritissimus anatomicus et venerabilis senex." It is the structure of these valves, and their operation in the living subject, which furnish the last proof of the circular motion of the blood.

Harvey has little to add to the anatomical description of the valves as given by Fabricius; but he declares that they offer a complete, not a partial, obstacle to the passage of blood from within outward. He has often tried this experiment. If a probe be passed into the vein, in a direction from its trunk toward its branches, however carefully managed it will never go far without being arrested by a valve. But if turned in the opposite direction, from the branches toward the trunk, it passes with entire ease. In many instances the valves are arranged in pairs, with their corresponding edges so closely adapted that when shut, their line of junction is imperceptible; and yet when an instrument is introduced from the periphery toward the centre, they yield at once, and open without difficulty. He believes accordingly that the valves oppose an absolute resistance to any movement of blood from the larger veins to the smaller; allowing it, on the contrary, free passage from the smaller to the larger.

But the fact can be more clearly shown by experiments on the veins during life. Let the arm be tied above the elbow with a moderate ligature, as for venesection. The superficial veins will then show themselves, with their lateral branches of communication more or less turgid, and with spheroidal swellings or "nodes" at various points, marking the situation of the valvular attachments. Now if the finger be firmly placed on one of these veins, immediately below such a node, and then moved downward two or three inches away from the node and along the track of the vein, so as to empty it of blood for this distance, the vein will remain empty between the point of its compression by the finger and the node above. No blood will come into it from the upper part of the vein; and even if, with the fingers of the other hand, you stroke the upper part of the vein downward toward the node, you cannot force the blood through, and the vein below still remains empty. This shows that the valves, in a healthy, unopened vein, are an impassable obstacle for the blood from above downward. On the other hand, the moment the finger is removed from the vein below, it is at once refilled from this direction.

The experiment may be varied by first compressing a vein several inches below a node, and then rubbing it upward, with the fingers of the other hand, toward the node. This will empty its included portion; the blood passing through the valves of the node into the vein above, but none of it returning in a downward direction. When this has been done, lift up the compressing finger for a moment, and let the vein fill from below. Then empty it as before, by pressing the blood upward past the valves. Then repeat the former operation; and so on, computing the quantity of blood which passes this small section of the vein at each repetition, and you will begin to appreciate the volume of the mass returning from all quarters toward the heart. And if you object to the possible violence or abnormal condition of such an experiment, then, without any such violence or abnormal condition, empty a superficial vein upward by pressure between two valvular nodes, and see how rapidly the blood from below follows the retreating finger. After that, there will be little probability of any remaining doubt.

Beside the proofs and arguments already cited, others are given in the latter part of the work, from various physiological and pathological phenomena, the requirements of surgical practice, and the details of anatomical structure, in both fœtal and adult life. But these are only in the way of confirmation; and with the conclusion of his thirteenth chapter, on the valves of the veins, the reader feels that Harvey's work is done. He has gone, in orderly succession, through the entire round of the vascular system, demonstrating, at each step, the physical action of the parts, and the movement and volume of the circulating blood; and he leaves the subject at last, with a wholly new interpretation of the action of the heart and bloodvessels.

There are two features remaining, in connection with Harvey's doctrine, of sufficient interest to attract the reader's attention.

The first is that Harvey did not believe in the *terminal anastomosis between arteries and veins.* Such an anastomosis had been admitted almost from time immemorial; and it had been especially corroborated by Galen* from experimental evidence. For a new discoverer, filled with the conviction of a perpetual transfer of blood from the arteries to the veins, we should anticipate that he would seize with avidity on the doctrine

* Galen. Opera Omnia, vol. v., p. 165.

of their communication. But these anastomoses seem to have been too hypothetical for Harvey's fancy. The actual passage of the blood between the two sets of vessels was established on other evidence, too decisive for doubt. But the precise method of its transfer had not been demonstrated; and Harvey preferred the idea of a filtration through the porosities of the organs, to that of communication by vascular orifices. Throughout his work, *De Motu Cordis et Sanguinis*, he is careful to speak of both methods as possible means of transudation for the blood, without deciding positively in favor of either (91); but in his first letter to Riolan, published in 1649, he declares that notwithstanding he has endeavored, with all due diligence, to discover the vascular anastomosis, he has never been able to do so.

"I could never find," he says, "arteries and veins communicating with each other by orifices, though I might easily learn of them from others, who think so much of Galen that they will make oath to whatever he says. Neither in the liver, the spleen, the lungs, the kidneys, or any internal organ is there any anastomosis; although, after boiling them until the whole parenchyma is friable, so that it can be shaken like dust or detached with a needle from the vascular fibres, I have been able to see plainly all their filaments of subdivision and hairy tufts. I can therefore confidently assert that there is no anastomosis, either of the portal vein with the vena cava, of the arteries with the veins, or of the ramifications of the biliary duct, which are distributed through the whole under part of the liver, with the veins" (92).

If Harvey had possessed the finer methods of anatomical research of our own day, he would have seen these vascular communications which he refuses to acknowledge. But with his means of investigation they could not be recognized; and he was perhaps only sensible and judicious not to accept them without better evidence. It may be remembered, also, that the communications now known to exist are not, after all, the simple anastomoses admitted in Harvey's time. They are a network of capillary bloodvessels, differing in structure from both arteries and veins; and the blood in traversing them suffers a delay, somewhat like that which it would meet with in filtering through the porosities of a permeable tissue.

Secondly, Harvey's discovery introduced into anatomy a new definition of the terms, artery and vein. Previously, a "vein" was a vessel containing venous blood; and an "artery" was a vessel containing spirituous blood. For the most part, the veins, under this nomenclature, had thin and flexible walls, while those of the arteries were thick and resisting. But there was a notable exception to this rule in the case of the lungs, where the texture of the two vessels was reversed; and for that reason the vessel carrying venous blood to the lungs was the "vena arteriosa," while that carrying spirituous blood to the same organs was the "arteria venosa." According to Harvey, on the other hand, the arteries, which are always the same in texture, carry blood from the heart to the organs; the veins, also all similar to each other, bring it from the organs to the heart. Consequently, the "vena arteriosa" becomes the pulmonary artery, and the "arteria venosa" the pulmonary vein.

CHAPTER IX.

THE DISCUSSION AND THE VERDICT.

PRIMEROSE. RIOLAN. BARTHOLINUS.

THERE is no circumstance of greater interest in the history of the circulation than the impression produced by the appearance of Harvey's book. Its doctrines implied, by their novelty, an entire revolution in the physiology of the blood and bloodvessels; and they were supported by an array of evidence which gave them an unmistakable claim to attention. They had been already presented in the author's lectures, and were, of course, known to his associates in the College of Physicians; but they had received in this way only a limited publicity, and were liable at any time to revision or modification. With the publication of his book, they assumed a definite and permanent form, and were laid before the profession for their final consideration.

The first work which appeared on the subject, after that of Harvey, was one in opposition to it, by JAMES PRIMEROSE, a medical practitioner of some note, living in Yorkshire. Primerose was of Scottish parentage, but born in France, where he graduated in medicine, in 1617, at the university of Montpellier. Soon after receiving his degree, he went to England and engaged in practice, in which he seems to have been very successful. He was a man of good education, and a ready writer, with a rather unusual facility of expression. He published a number of medical works, two of which are said to have been much esteemed, namely, one on "Vulgar Errors in Medicine," 1639; and one on "Diseases of Women and their Symptoms," 1655. His treatise on the circulation * was his earliest production. Like Harvey's book, it is dedicated, first to the King, and next to the President and Fellows of the College of Physicians. The author is induced to write, because the "learned and ingenious doctrine" of the circulation of the blood seems to him "of doubtful value to the medical art," and "beset with most serious difficulties;" which he desires to bring forward, that the truth may be made evident by their discussion.

The book of Primerose is a protest and an argumentation. He is opposed to "too great license in impugning the doctrine of the ancients," and he enters at length into the objections against the new system. This part of his work is very instructive, as showing the obstacles which delayed at that time the acceptance of Harvey's views.

One of the most important of these difficulties was the deeply rooted belief in two different kinds of blood, contained in separate vascular systems, and destined for essentially different purposes. The thick, dark-colored, and sluggish venous blood was for the material nourishment of the parts; the highly elaborated,

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* Jacobi Primirosii Exercitationes & Animadversiones in Librum Guilielmi Harveii de Motu Cordis et Circulatione Sanguinis. London, 1630.

It appeared subsequently, in company with the work of Parisanus, under the title: Guilielmi Harveii de Motu Cordis & Sanguinis Anatomica Exercitatio. Cum Refutationibus Æmylii Parisani et Jacobi Primirosii. Lugd. Bat., 1639.

scarlet, and spirituous arterial blood supplied the stimulus of vitality for their more active functions. The mobility of arterial blood was therefore, in great measure, a property of its own, depending on its ingredient of vital spirits; the "spirits" being everywhere the *moving forces*, according to Hippocrates. This made it unnecessary to assume a physical propulsion by the heart, to account for the motion of the arterial blood; and this is the reason, according to Primerose, that when an artery is opened, the blood escapes with such impetus. It is ejected by the expansive force of its vital spirits, not by a mechanical impulse from the heart. Consequently, it is not surprising that the blood escapes with greater violence at the time of the arterial diastole; especially as it moves from all the other arteries at once into the wounded vessel.

The spirituous quality of arterial blood gave an air of probability to other points in the accepted belief, such as the filtration through the cardiac septum. This filtration took place in very small quantity; but when the venous blood, once introduced into the left ventricle, became impregnated with air, the combined product of the two, that is, spirituous blood, was much more abundant. "Blood," says Primerose, "is denser than air; but when it becomes attenuated, a very little blood swells by rarefaction into a large mass. Philosophers tell us that one volume of water will make ten volumes of vapor; consequently, only a small amount of blood is needed for the left ventricle." *

Another obstacle for the new doctrine was the sup-

* Primerose. Exercitatio xxv.

posed absence of free communication between the arteries and veins. Harvey did not admit the mutual continuity of these vessels, and regarded the blood as passing from one system to the other through the substance of the tissues. But if the blood, as he maintained, were carried through its course, in a continuous round, by the heart's impulse, how could this impulse be effective in the veins beyond the intervening tissues? And if it were so effective, why did not the veins pulsate as well as the arteries? In the pulmonary circulation there were additional difficulties, which are duly set forth by Primerose. "In case the blood follows that course," he says, "it must, in the first place, escape from the vena arteriosa, notwithstanding the thickness and density of its coats; which can only take place by anastomosis, or else by rupture or exudation. But that is nothing to what follows; for, in the next place, it must find its way to the arteria venosa and penetrate its walls. Why should it get into the arteria venosa rather than into the bronchial tubes? In hemoptysis, in purulent expectoration, in pleurisy, we see the blood and pulmonary humors ejected by the bronchi and trachea. How fortunate would it be for such patients, if extravasated blood could get back into the arteria venosa."

Primerose states the propositions of Harvey in their regular order for special consideration, and he has no difficulty in seeing which are the important points in the argument. If his objections sometimes appear captious, they are often forcible, and occasionally rather unexpected, in their ingenuity and plausibility. For instance, he says, addressing Harvey: "You deny the existence of the porosities of the septum; but do you think it any more difficult for the blood to pass that way, than from the vena arteriosa to the arteria venosa through the pulmonary parenchyma? Certainly, the pores of the lungs are no less obscure than those of the septum."

In his seventh chapter, to show the possibility of the pulmonary circulation, Harvey adduces the transudation of rain water through the earth, of perspiration through the skin, of urine through the kidneys, and of the blood, with the products of digestion, through the liver. "But for those very reasons," says Primerose, "I wonder that you should deny its transit through the septum. If blood can pass through the dense and compact liver, from the portal vein to the vena cava, why not through the septum from the right ventricle to the left?"

When describing the peculiarities of the fœtal circulation, in his sixth chapter, Harvey shows how the blood passes from the veins to the arteries through the foramen ovale and the ductus arteriosus; and he asks why Nature should not accomplish the same transit through the lung, after the fœtal passages are closed. "To that," says Primerose, "I should reply, that it is because Nature chose to do differently. The question is about the course of blood in the adult, and you have described it as it is in the fœtus. As to its significance that is a point on which anatomists greatly differ."

The author is especially urgent in his criticisms on Harvey's ninth chapter, in which it is maintained that the blood is transmitted, by the heart's pulsation, from the venous to the arterial system *in greater abundance* *and rapidity than can be accounted for by the whole mass of blood or the daily supply of aliment.* "This," says Primerose, "is the turning point of the whole question. If fairly proved, the thing is done, and no further discussion will be necessary. For if the entire blood really pass in this way from the veins to the arteries, it must either all collect in the arterial system, which we know is not the case, or else it must come back by the veins. But physicians do not believe the *whole* of the blood to be made spirituous in the left ventricle, but only a part of it; that, namely, which is required for elaboration, with the aid of the inspired air, to produce arterial blood." The expansion and attenuation of blood, when it becomes spirituous, is illustrated by the increased volume of honey or milk in a state of ebullition, when a very small quantity of the original liquid will swell so as to overflow the containing vessel. Harvey says he has found in the left ventricle no less than two ounces of blood. It may be true, replies Primerose, that the ventricle contains so much; but that quantity will be sufficient for very many pulsations. The left ventricle attracts blood only as it is required for elaboration; and as for the quantity expelled at each cardiac contraction, he dissents entirely from Harvey's estimate, that this is to be measured in ounces, or drachms, or scruples. It is, perhaps, not even a grain, but only a third or a quarter of a grain; and this quantity of blood can certainly be supplied from the liquids absorbed in digestion.

It is evident from the above, and other similar passages in Primerose's book, that in the combination of blood and spirits, to make arterial blood, the resulting compound was supposed to consist in a small proportion of blood and a much larger proportion of spirits. This is the reason, according to Primerose, why, after death, the arteries are nearly empty, though the veins are full of blood. The spirits which the arteries contained have then been dissipated, and the blood in these vessels has subsided to its original volume.

The last proof adduced by Harvey that the blood returns through the veins, from the periphery toward the heart, depends on the existence and action of the *venous valves.* But this, according to Primerose, has no force. First, because the blood is supposed to return through all the veins, while only those of the limbs and part of the trunk are provided with valves. You cannot, in a case like this, make an inference from the particular to the general. How can the valves in the veins of the limbs show an inward current in the veins of the portal system or the head, where there are no such valves? The valves in the veins of the limbs, according to Primerose, are only exceptional, and intended to delay the afflux of blood to the muscular parts, when attracted by unusual activity of motion. If they were for the purpose of preventing an outward flow and favoring an inward current, why should they not be found in the portal veins as well as in those of the limbs? As for Harvey's experiment with the probe, which is arrested by the valves when pushed from within outward, that does not show that blood could not pass, in some measure, even when the valves are closed. Like a stricture of the urethra, which may retard the flow of urine without obstructing it completely, the valves do not at any time quite prevent the afflux of blood by the veins, though they regulate it according to circumstances.

One cannot help giving Primerose the credit of sincerity. His incredulity seems due to a wrong estimate of Harvey's proofs, rather than to intentional disregard of their value. Although he quotes a number of experiments in favor of his own opinion (93), it does not appear that he performed any of them himself, or that he attempted to verify those of Harvey. An experiment actually witnessed often carries a very different conviction to the mind from one that is taken on hearsay; since objections, which might otherwise seem plausible, are disposed of in advance by the nature of its conditions and its results. Primerose was well equipped with the armament of medical literature, and he could use it with skill in the treatment of controverted topics; but he was satisfied with the existing doctrines of physiology, and he could see in the new system only uncertainties and defects.

A very different commentator appeared some years afterward in the person of *Plempius*, professor of Practical Medicine in the university of Louvain. Plempius, who was a native of Amsterdam, began his medical studies in Leyden, and finally graduated at the university of Bologna. After practising for a few years at Amsterdam he became, in 1634, professor at Louvain, where he passed the remainder of his life. He is principally known from two of his publications; one on ophthalmology, and one on the principles of medicine. In the last of these works* he maintains

* Vopisci Fortunati Plempii Amstelredamensis Fundamenta Medicinæ. Editio altera, recognita, interpolata, aucta. Lovanii, 1644. Lib. ii., cap. vii. De Sanguinis Circulatione.

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the doctrine of the circulation of the blood; having been convinced of its truth, after receiving it at first with incredulity.

This treatise is especially interesting from the vigorous and outspoken style of the author, and from its faithful presentation of the subject. Plempius takes the reader fully into his confidence; and shows him plainly the doubts experienced by a well informed and candid inquirer, and how they were set at rest by means of direct observation. He gives a succinct account of Harvey's doctrine, which, he says, had been supported by its author with so many plausible reasons, that it was already beginning to find favor with not a few learned men. As for himself, "At first," he says, "I did not believe in it, as I showed publicly, both in words and writing. But afterward, on going to work in good earnest to refute and explode it altogether, I find I am refuted and exploded myself. Its evidences are not persuasive; they are irresistible. I have diligently scrutinized them all, in living dogs which I opened for the purpose, and find them to be perfectly true."

He goes on to enumerate these evidences, from which the doctrine of the circulation must be admitted; beginning with the main proposition, that the blood is transfused by the heart's action, from the vena cava to the arteries, more abundantly than can be accounted for by the daily supply of nutriment. He makes this calculation in the same manner with Harvey, and comes to a similar result. "What are we to do now," he says, "to save the ancient doctrine? Where does all this blood come from, to supply the heart? Certainly not from the aliment. For the same thing happens when no food has been taken for a couple of days. There is no other possible explanation than this, that the blood which is expelled from the heart into the arteries again insinuates itself into the veins, and thence hurries back to the heart, to be once more refunded into the arteries."

This is the only conclusion that seems reasonable; and furthermore, "It must be adopted, because experiment makes it imperative." He details Harvey's observation on the vena cava of the serpent, showing that obstruction of this vessel arrests the return of blood, which recommences on removing the compression; and then adds one of his own on the crural vein. "Or uncover," he says, "in a live dog, one of the larger veins in the groin, tie it with a thread, or take it up with forceps or the fingers, and you will see the upper part of the vein toward the vena cava become collapsed and emptied. The other part of it, on the contrary, toward the foot, will swell up, until from repletion it appears harder even than the artery; but take away the ligature, and the blood at once moves upward, relieving the vein from its hardness and distension."

The same thing may be seen in the veins of the arm, when secured by a bandage for bloodletting; and this proof is still more accessible, for nearly every one sometimes does the operation of venesection, or, at least, may see it done by others. Now when such a bandage is placed on the arm, what happens? The veins below the ligature become tumid. But why should they not swell above the ligature, if the blood naturally comes down that way? Furthermore, when the vein has been opened and the blood is spouting out, if you compress the vein a short distance below the orifice, the blood stops; but if you compress above the wound, it keeps on running. What could show more conclusively than this, that the blood escaping at the wound does not come down from above, but comes up from below? Do you ask anything better? Cut across, in a live dog (as Plempius has done several times), the crural vein, and you will see that there is no bleeding from the upper orifice, but plenty from the lower; while if the same thing be done with the jugular vein, all the blood comes from the upper orifice, and none from the lower. In his opinion, therefore, it is "decided and established, by these experiments, so sure, constant, unquestioned, and undeniable, that the blood flows through the veins to the heart, that it may again flow out from the heart into the arteries; that is, it moves in a circle."

But Plempius did not arrive at this conviction without some mental conflict. He could not easily divest himself of his "deeply imbibed" belief in the teaching of the ancients, and he labored to find some way of reconciling it with the facts. Might it not be that the heart discharged into the arteries at each pulsation much less than half a scruple; and that even this was nearly all spirits rather than blood? And might not the heart often dilate and contract without receiving or transmitting anything, as we see it do sometimes after it is cut out of the chest? In that case, the blood supplied day by day from the liver might be sufficient for the generation of vital spirits, and so for all the spirituous blood discharged into the arteries. As for the experiment of the bandaged arm, and the swelling of the included veins, perhaps that was because the blood was compressed below the ligature and could not escape, while above the ligature it had all the space of the other veins to relieve its tension.

This is the way that Plempius argued with himself; and he even says that in his lectures he could "satisfy his audience" with the same arguments. But on the whole they were hardly convincing, and he was obliged to confess that, "when duly considered, they did not help the cause of the ancients." For who but a blind man could believe that nothing but spirituous matter is sent from the heart into the arteries? Ocular examination shows that the arteries and the left ventricle both contain a ruddy liquid, which is as much blood as that in the veins; and what the ventricle contains must be expelled by its contraction. The arteria venosa is for the passage of blood as certainly as the vena arteriosa; that is made evident by vivisections, for all who have eyes to see. Consequently the arteries are distended by what is sent into them from the heart; and the heart and the arteries contract and dilate, not together, as formerly supposed, but alternately with each other. The arteries are dilated when the heart contracts; and when the heart is dilated the arteries contract. There is no such thing as arterial pulsation, except from the force of the blood propelled by the heart.

The proposed explanation of the swelling of the veins below a ligature is also futile. If it were true, then they would swell in a dead man as well as in a live one, under the same conditions. But nothing of the kind takes place. Besides, it is not necessary to bind the whole limb. A single vein, constricted by a thread, becomes swollen below by the blood poured into it from the artery; and this is plainly shown by the fact that, if the bandage be tight enough to compress the artery, there is no swelling of the part, because no more blood flows into it.

One difficulty in accepting the doctrine of the circulation, with Plempius as well as others, had been the following. If the blood circulated, as claimed by Harvey, going out by the arteries and returning by the veins, then all parts of the body must be nourished by the same blood, and, moreover, by spirituous blood only. But that was an unheard of thing, and contrary to all the ideas then entertained in regard to nutrition. However, Plempius remembers that its being up to that time unheard of does not necessarily make it false. The venous blood, previously thought to do most of the work of nutrition, must itself supply a great variety of parts; and why might not arterial blood do the same? In fact there is no reason for believing the two kinds of blood radically different. If you take arterial blood and venous blood from the same animal, and leave them until they have cooled and coagulated, you will hardly be able to tell one from the other.

There are several minor objections which Plempius enumerates and refutes with equal success. His remarks are everywhere to the point; and his terse and cogent reasoning must have had much influence in winning adherents for the new doctrine.

In the meantime the question had been debated by a number of other writers, who expressed their opinions, either for or against the circulation, in special treatises or in published letters on the subject (94).

But the most important, among those who dissented from Harvey's views, was RIOLAN, professor of Anatomy and Pharmacy in the Parisian School of Medicine, Dean of the Faculty, a man of great influence among his colleagues, and generally regarded throughout Europe as the first anatomist of his day (95). He was a native of Paris, where he became at an early age professor in the Medical School, as his father had been before him. He was a prolific writer; no less than twenty-eight of his works being enumerated by his biographers, the most important of which were on anatomical and physiological subjects. His earliest book, a treatise on surgery, was published in 1601; but that which made his greatest reputation was his *Antropographia*, which appeared in 1618, and went through many subsequent editions. He was physician in chief to the Queen mother of France; and it was mainly his influence in this position which resulted in obtaining a royal edict for the establishment of the Garden of Plants.

Riolan was the zealous advocate of conservatism in medicine; but by no means always in an excessive or unreasonable way. He was the leader and mouthpiece of the Paris faculty, in opposition to the noisy pretensions of the *medical chemists;* who at that time claimed to revolutionize the theory and practice of medicine, though they were hardly better than so many alchemists. Riolan defended the ancient system against these unprofitable crudities with ardor and success. When a number of large-sized bones were brought to Paris, and exhibited as the remains of a certain legendary *giant*, he pronounced them the bones of an animal; and soon after published his *Gigantologie*, showing that the men of unusual stature in ancient times were no larger than those of modern periods, and that in all times there have been instances of both giants and dwarfs. He was the first to give a genuine interpretation to the story, repeated by various writers, of men with *hairy hearts* and corresponding audacity. He declared this hairy covering to be only coagulated fibres from the pericardial liquid.*

Riolan saw that the evidence of a circular motion of the blood was too strong to be disregarded. He comprehended its importance, and believed in its value as a discovery. But he was fervently attached to the ancient system of medicine, and he could not tolerate the idea of its complete overthrow and disruption. According to the doctrine of Harvey, this seemed inevitable. For if all the blood in the body were hurried through the vessels, from the arteries to the veins, and thence back to the heart and arteries, in an incessant revolution, where was the opportunity for its sanguification in the liver, and the expulsion of its impurities by the abdominal organs? How could it provide for the nutrition of the parts? How were the peccant humors of the blood to be collected in particular localities, as in gouty and rheumatic affections, or concocted and eliminated by the emunctories? How could blood-letting cause derivation of blood from the affected part; or how could local depletion or revulsive applications be of any service in the treatment of disease? And, finally, what became of the distinction between arterial and venous blood, and the special office of each in the vivification and nourishment of the tissues?

* Casp. Bartholini Institutiones Anatomicæ, Lugd. Bat., 1641; lib. ii., cap. vi.

Beside, the advocates of Harvey's doctrine did not agree with each other in certain particulars; such as the quantity of blood propelled at each cardiac pulsation, the time required for its return to the heart, the immediate cause of the heart's action, and the nature of the arterial movement. The passage of blood through the lungs, furthermore, was an unnecessary supposition for its circular motion through the body. Galen's doctrine of its passage through the interventricular septum was more probable, and attended with none of the dangers or inconveniences of a pulmonary circulation. Why should we deny the transit of blood through the septum, when we know that serum can pass through the walls of the veins, or penetrate the bones from their medullary cavity? And if the blood pass in a constant stream through the pulmonary vessels, why are not wounds of the lung always fatal from incontrollable hemorrhage?

Riolan accordingly refuses to accept the "Harveian circulation," and offers, instead, one of his own;* which shall have the double advantage of preserving the time-honored Galenic system in its essentials "safe and inviolate," and of avoiding at the same time the improbabilities and obscurities of the recent doctrine.

First of all, he rejects the circulation of blood through the lungs, for the reason already given; and adheres to the dogma of its transudation through the interventricular septum, the conveyance of air from the lungs

* Encheiridium Anatomicum et Pathologicum. Paris, 1648. Also, Opuscula Anatomica Nova, Instauratio magna Physicæ & Medicinæ, per novam Doctrinam de Motu Circulatorio Sanguinis in Corde. Authore Joanne Riolano, Professorum Regiorum Decano. London, 1649.

by the arteria venosa, and the formation of spirituous blood in the left ventricle.

Secondly, the liver is still the organ of sanguification. The blood is formed in this organ from the daily products of digestion. A part of it is delivered into the vena cava to replenish the system at large; the rest is contained in the portal system to supply the abdominal organs. The hepatic vein and the portal vein, therefore, in the liver, have no communication with each other; and the blood of the portal system is wholly disconnected from that of the vena cava. Consequently there is no "circulation" of the blood in the abdominal region, since none of it returns thence to the heart; all of it, both in the portal vein and the mesenteric arteries, being consumed in the acts of nutrition and secretion.

Thirdly, the arterial blood of the left ventricle, replenished from the vena cava through the interventricular septum, is sent out by the arteries to all parts of the body and limbs. Here a portion of it passes through the vascular anastomoses into the veins, which are thus filled quite to their extremities. Fully one-half this blood, that is, all contained in the smaller venous branches and ramifications, does not circulate; it is employed for local nutrition, and remains in the vessels of the part. The rest of it fills the vena cava and its main divisions from the neck downward, and through these channels returns to the heart, where it passes through the interventricular septum, acquires fresh heat and vitality in the left ventricle, and again passes out by the arteries as before. This is Riolan's "new circulation;" and this is why he calls it the "motus circulatorius sanguinis *in corde*." There is no movement of the blood through the lungs or through the abdominal organs; and only a portion of it returns by the veins in order that it may pass through *the heart*, where its spirituous quality is renovated and its animating power restored.

By this means all uneasy doubts are satisfied. As the blood does not circulate through the lungs, there is no danger of its causing ecchymoses or aneurisms in these organs, or being infected with their mucous impurities or excretions. The incredible rapidity of the circulating current, as estimated by its advocates, is also reduced to a more moderate computation; for Riolan believes that the heart admits and expels only one or two drops of blood* at each pulsation; which would amount in fifteen or sixteen hours to hardly more than twenty pounds. Thus that part of the blood which returns to the heart would pass through the round of the circulation only two or three times a day, instead of forty or fifty times, as claimed by Harvey. Furthermore, the established methods of practice might continue in use; for since a large proportion of the nutrient blood remains at rest in the veins of each part, it may be influenced by venesection and local applications, as before.

It does not appear that this system obtained general support, even among the opponents of Harvey. It was discussed in the meetings of the Paris Faculty, and was defended by its author with much persistence and reiteration. But it did not satisfy the extreme adherents of traditional dogmas, and it could hardly find favor with those who believed in the experimental

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* Opuscula Anatomica Nova. Liber de Circulatione Sanguinis, cap. xv.

development of a new physiology. Riolan remained steadfast in his opinion, and would never allow of any further concession, to the detriment of Hippocrates and Galen.

Shall we blame Riolan for his obstinacy in resisting the doctrine of Harvey? On the contrary, it is an advantage to medical science that there are always some who are ready to question and doubt such an innovation; for they compel it to run the gauntlet of adverse criticism, before being accepted by the profession at large. If it fail to bear this test, the cause of failure is in its own demerits, and it ought not to succeed. If founded in truth, it is all the better for being subjected to opposition and scrutiny; for they prove its reality, and establish it at last upon evidence that none can dispute.

The publication of Riolan was soon followed by a reply from one of his old pupils and admirers, Paul Maquart Slegel, of Hamburg.*

Slegel says that when, some months before, a friend brought him from Paris a number of recent medical works, he was greatly pleased to see among them one by Riolan, on the *Circular Motion of the Blood;* for he thought that the authority of so consummate an anatomist, and the example of the flourishing Parisian School, would now suffice to settle the dispute and secure general acceptance for the doctrine of the circulation. But on reading the book he found, to his disappointment, that its influence was in the opposite direction; and that the true doctrine of the circula-

* Pauli Marquarti Slegelii, Med. Hamburgensis, De Sanguinis Motu Commentatio, in qua præcipue in Joh. Riolani, V. C. sententiam inquiritur. Hamburgi, 1650.

tion, so far from being corroborated, was hampered with objections and disputations, and arrested, so to speak, in the middle of its course. This gave him much uneasiness. "Is it possible," he says, "that I have been, for the last twenty years, all wrong in believing this doctrine, which I have taught and defended with so much ardor?" But his belief had been founded on observation and experiment. And after repeating the experiments, and subjecting them to a second examination, he obtained the same results, and his confidence was reëstablished. So he determined to write a letter of remonstrance to Riolan; but the subject grew under his hand, as often happens, and ended in the production of a volume.

Slegel goes over the ground covered by Riolan step by step, refuting his opinions with fairness and judgment; though he hardly succeeds in making the subject equally attractive. His book shows somewhat of the prolixity and taste for argumentation which he imputes to Riolan, but without the talent and vivacity of the French professor.

But the most appropriate person, to speak for the doctrine of Harvey, was Harvey himself; and he accordingly replied to Riolan in two discourses,* which appeared a short time before the work of Slegel.

Somewhat to his surprise, the reader does not take much interest in Harvey's "Exercitationes ad Joannem Riolanum." They are in response to a theoretical

* Exercitationes duæ Anatomicæ de circulatione sanguinis: ad Joannem Riolanum, Filium, Parisiensem. These discourses are contained in the edition of Harvey's works by the London College of Physicians, 1766; and in the English version of Dr. Willis, published by the Sydenham Society, 1847.

system which is unsupported by material evidence, and which represents hardly anything more than the opinions and inferences of its author. Harvey's reply occupies a similar ground; and it is mainly in the style of controversial dialectics, rather than that of experimental demonstration. In fact, the demonstrative part of Harvey's work had been done before. His book, *De Motu Cordis et Sanguinis*, had presented the subject in so simple and concise a manner, that its function was complete. Why should he amplify it by a repetition of the same proofs, or by stating them again in different form? He adduces a number of observations which he had formerly omitted, as being "redundant or useless" for the doctrine of the circulation; but they could have little weight with those who were not already convinced on other grounds. The debt which physiological science owes to Harvey would have remained equally great if he had made no addition to his first essay.

It is in one of these Discourses, as already quoted (page 188), that Harvey expresses his disbelief in the supposed arterial and venous *anastomoses*. He declares that neither Galen nor Riolan has ever made these communications perceptible to the eye, and that they are admitted only as matter of inference. This leads to the curious result, that Harvey, who maintains the circulation of the blood, denies the fact of vascular anastomosis; while Riolan, who denies the circulation, accepts the existence of the anastomoses. The reason is, that Harvey believes the whole of the blood to pass from the arteries to the veins through the intervening tissues for their sustenance and growth; while Riolan maintains that a part of it escapes from the arteries into the veins without reaching the tissues, and goes back to the heart for spirituous renovation.

So far, the doctrine of the circulation had made greater progress in the north of Europe than in its middle and southern portions. But it now received powerful aid in France from the advocacy of *Pecquet;* who was led to investigate the movement of the blood in connection with that of the chyle. The lacteal vessels had been discovered by Asellius in 1622; but as he saw only their origin from the intestine and their convergence toward the root of the mesentery, he inferred that they continued their course to the liver, after the manner of the mesenteric veins. Pecquet, while a student in the university of Montpellier, in 1647, discovered the *thoracic duct*, in an animal opened during digestion. In repeated experiments, by tracing this vessel downward, he reached its origin, the *receptaculum chyli*, into which the lacteals empty themselves; and by tracing it upward he found its termination in the subclavian vein. Consequently, the chyle in the lacteal vessels is carried, not to the liver, but through the thoracic duct to the great veins near the heart; and its movement is directly connected with that of the blood in these veins.

In Pecquet's treatise,* he demonstrates "the circular movement of the blood throughout the animal body" by the effect of ligatures on the arteries and veins. Most, if not all these experiments had been done before; but he gives them the guarantee of his own testi-

* Ioannis Pecqueti Diepæi Experimenta nova anatomica, quibus incognitum hactenus Chyli Receptaculum, & ab eo per Thoracem in ramos usque Subclavios vasa lactea deteguntur. Ejusdem Dissertatio Anatomica de Circulatione Sanguinis & Chyli Motu. Parisiis, 1651.

mony, and shows much originality in their arrangement and in the directness of his conclusions.

He begins with the arteries and veins in general. If, in the living animal, a ligature be placed on the crural, brachial, or carotid *artery*, the vessel is emptied beyond the ligature, but becomes turgid on the side toward the heart; and if it be opened beyond the ligature, there is no bleeding, while a puncture on the side toward the heart causes abundant hemorrhage. But a similar experiment on the crural or brachial *vein* gives the opposite result. The vein collapses toward the heart and swells toward the periphery; and a puncture below the ligature is followed by hemorrhage, but above it has no effect. To make sure that the blood which escapes from a wounded vein has come from the arteries, he places a ligature, while the hemorrhage is going on, upon the corresponding artery. When this ligature is tightened, the bleeding from the vein first diminishes, and then stops; but when it is relaxed, the hemorrhage begins again as vigorously as before.

Pecquet supplements these results by an ingenious experiment, applied to the exceptional cases where a vein bleeds from a puncture above the ligature.

"You need not be disturbed," he says, "because sometimes, though rarely, there is a certain amount of bleeding from the vein above the ligature. This comes from some of its branches opening, here and there, into the main trunk; and I do not wish you to take my word for it, but hear the proof."

"I was operating, one day, in the way described, and had punctured the crural vein on both sides of the ligature; when, unexpectedly, I saw a flow of blood, apparently continuous, not only below the ligature, but also above it. I then followed the vein upward as far as the division of the iliacs, tying its small branches as I met with them here and there, until they were entirely closed; when the flow of blood finally ceased. The vein remained empty from the ligature upward, to the situation of the valve in the groin; and this valve, obstructing the vein completely when I pressed it above, showed conclusively that the blood has no passage through the veins from above downward." *

He then turns his attention to the arteries and veins of the abdominal system, and soon finds that the cœliac and mesenteric arteries follow the general law: that is, they become turgid above the ligature, and flaccid below it. But the veins of this region show a certain peculiarity. When a mesenteric branch of the portal system is tied, the vein swells, it is true, below the ligature; but, at the same time, it is by no means completely emptied in the direction of the liver, and furthermore it bleeds when punctured on either side of the ligature.

This brings to his mind the opinion of Riolan, that the blood of the portal vein does not pass through the liver into the vena cava; and he "would have been deterred, by the authority of so great a man, from further experiments," if he did not feel that he ought to follow the investigation throughout, and "subject it fully to the severe judgment of the senses."

Accordingly, he returns to the examination of the portal system. "I secured by a ligature the mesenteric branch of the portal vein at a distance of three fingers' breadth from the liver; and then, at a similar distance, placed a ligature upon the splenic branch, so that it

* Pecquet. Dissertatio anatomica de circulatione sanguinis, cap. i.

could be tightened or relaxed at will. I had hardly drawn this second ligature close, when the whole portal trunk, from the ligatures to the liver, became collapsed and exsanguine; both of its branches, with their ramifications, being at the same time crowded with blood from the intestines, mesentery, stomach, and spleen."

"If I relaxed either ligature, the exhausted portal trunk was at once refilled, to be emptied again when the ligature was tightened; until, by frequent repetition of the experiment, there was no longer any doubt of the abundant and rapid flow of blood from the portal vein into the liver." *

A similar trial with ligatures, on the hepatic vein above the liver, proved in the same way that the blood which enters this organ by the portal vein below passes out by the hepatic vein above. The circulation through the abdominal organs, notwithstanding its local peculiarities, comes therefore, at last, to the same result as that through the body at large; and the blood of the portal system, like that everywhere else, is continually supplied from the arteries, and as continually returned through the veins.

Finally, the pulmonary artery and the pulmonary vein, subjected to the same test, act in a similar way: that is, the artery swells from the heart toward the ligature, and collapses between the ligature and the lungs; while the vein becomes turgid from the lungs to the ligature, and collapses between the ligature and the heart. The course of the blood is, therefore, from the right ventricle through the pulmonary artery to the lungs, and from the lungs through the pulmonary vein to the left side of the heart.

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* Pecquet. Dissertatio anatomica de circulatione sanguinis, cap. ii.

Pecquet, accordingly, followed in his experiments the opposite route to that taken by Harvey. The investigations of Harvey began with the heart and the pulmonary circulation, and finished with the return of blood from the periphery by the veins. Pecquet began with its movement through the vessels of the periphery, and finished with that through the lungs and heart.

The gradual adoption of Harvey's views may be traced almost continuously in successive editions of the anatomical textbook of BARTHOLINUS. Caspar Bartholinus was professor of Medicine in the university of Copenhagen from 1612 to 1623. His *Institutiones Anatomicæ* were first published in 1611, and afterward in 1626 and 1632; the last issue being four years after the publication of Harvey's book, in 1628. But Bartholinus died in 1629; and it could hardly have been expected that he should so soon indorse the most radical innovation in modern physiology. In his work the structure and uses of the heart and bloodvessels are set forth clearly and concisely, according to the classical doctrine of the time. The heart is "the abode of life and of innate heat." Its uses are: 1. To elaborate the vital spirits; 2. To prepare blood for the nutrition of the lungs; and 3. To preserve the blood from putrescence by its incessant pulsation. Its diastole draws blood from the vena cava into the right ventricle, and air from the lungs through the arteria venosa into the left ventricle. Its systole discharges blood from the right ventricle to the lungs by the vena arteriosa, expelling at the same time from the left ventricle vital spirits into the aorta, and spirituous blood with fuliginous vapors through the arteria venosa to the lungs. The venous valves are for strengthening the veins, which are so much thinner than the arteries, and especially for opposing a too abundant afflux of blood to the limbs when in a hanging position or in active motion.

Thomas Bartholinus, one of the discoverers of the lymphatic system (96), was the son of the preceding. He studied under his father, and, like him, became professor in the university of Copenhagen. He continued the editions of his father's work; introducing at first notes and appendices relating to matters of recent interest, and afterward transforming the whole into his own book, with the gradual accumulation of new material and the increasing importance of his own discoveries.

The first edition issued in this way appeared in 1641, under the title *Casp. Bartholini Institutiones Anatomicæ, novis Recentiorum opinionibus & observationibus, quarum innumeræ hactenus editæ non sunt, figuris que auctæ, ab auctoris filio, Thoma Bartholino.* The progressive policy of the editor is indicated by a design on the frontispiece of a bird in full flight, with the legend MOVENDO. In his appendix to the sixth chapter of the second book in this edition, devoted to the pulse, he says, that William Harvey considers the pulsation of the heart as excited by the influx of blood from neighboring parts and its consequent distention; an opinion which Bartholinus thinks commendable for its simplicity, since we "ought not to multiply causes unnecessarily." However, reasons may be adduced in favor of other explanations; and, as the question is not to be determined by his judgment, he "will leave it to those who are more learned." In a note on the interventricular septum and the filtration of blood through its porosities, he says, although these foramina are imperceptible, "neither are there any visible channels for the passage of perspiration through the skin, or of blood through the parenchyma of the lungs, from the vena arteriosa to the arteria venosa." To the function of the vena arteriosa, for supplying blood for the nutrition of the lungs, he adds, "and, according to the opinion of more recent writers, to transmit it, through the arteria venosa, to the left ventricle of the heart." In the body of the work he does not further modify the physiology of the heart and bloodvessels; but, after the chapters on the veins and arteries, he introduces two letters, "De Motu Sanguinis," by Joannes Walæus, professor in the university of Leyden, who had embraced the doctrine of the circulation, and who was greatly esteemed in the profession. Bartholinus does this, as he says, because he does not yet feel himself capable of forming a decisive opinion on such new questions, "which should be submitted for adjudication only to men of the highest attainments." In these letters Walæus presents the evidence in favor of the circulation, and indorses it with the results of his own experience.

The next edition, of 1645, bears the same title, and contains no essential alteration of text on the question of the circulation. After the paragraph on the use of the venous valves, a note is inserted as follows: "According to Harvey, the valves have a different use, namely, to prevent movement of the blood from the larger veins into the smaller."

In 1651 the work appeared under a new title, as the *Anatomy of Thomas Bartholinus*, still constructed on the basis of the *Institutiones Anatomicæ* of his father, but enlarged and modified in accordance with the times, and still further designated as *Tertiùm ad sanguinis Circulationem reformata*. In this edition the author formally adopts the doctrine of the circulation. The text of his father's book, he says in the preface, which had become obsolete, he has remodelled and made his own, correcting what was contrary to later observations, and introducing all the recent discoveries; and, "what is of prime importance, the circular motion of the blood, maintained by Harvey and Walæus, and now accepted by most," he has "described in full, with great care."

The book was reprinted in several successive issues in the above form until 1673, when it was again revised, enlarged, and published with additional illustrations and the following title: *Thomæ Bartholini Anatome, ex omnium Veterum Recentiorumque Observationibus, ad Circulationem Harvejanam et Vasa lymphatica renovata.* The author, in the preface, calls this edition his "New Anatomy;" and says that he has finished everything "according to the Harveian circulation and the Lymphatic vessels," on which, as foundations, "the whole superstructure is built." By that time there was, probably, no difference of opinion, in the north of Europe, in regard to the circulation.

In Italy, Veslingius, who was professor of Anatomy in the university of Padua, had already, in 1647, approved the doctrine of the circulation,* though not in a very serviceable or decisive way. Trullius, however, at Rome, in 1651, maintained and demonstrated it with such success that, according to Sprengel,† his experiments convinced many who were before incredulous; and a few years later, in 1655, it was illustrated

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* Veslingius. Syntagma Anatomicum, cap. x., De Corde et Pulmonibus.

† Geschichte der Arzneykunde. Halle, 1827, Band iv., p. 85.

on the human cadaver by Domenico Marchetti, who had been the coadjutor of Veslingius, and who was then supplying the anatomical chair in the university of Padua. This circumstance is mentioned in the *Collection of Letters*,* by Thomas Bartholinus, in which so many other matters of historical interest are to be found. It appears that a certain Henry de Moinichen, a native of Copenhagen, who had studied under Bartholinus, was spending some time in Italy for further improvement. While at the university of Padua he witnessed this experiment, which he thought of sufficient consequence to make the subject of a letter to his former preceptor. "On the 13th and 14th of March," he says, "Dominichus Marchettus, although not professor, gave two lectures in the hospital, one on the circulation of the blood, the other on the lymphatic vessels. . . . . . He showed the circulation in the arm of a dead woman, by injecting warm water into the artery at the axilla, which returned by the median vein, where it was opened by a lancet."

In France, the resistance of official conservatism lasted longer; and the doctrine of the circulation was still excluded from the formal teaching of the Paris Faculty, as not in accordance with the tenets of medicine. But more liberal views were already common among the physicians of the day. This is proved by the success of Molière's admirable representations of the medical pedant and routinist,† and the readiness with which these satires were compre-

* Thomæ Bartholinæ Epistolarum Medicinalium à Doctis vel ad Doctos scriptarum Centuriæ i. & ii., Hafniæ, 1663. Cent. ii., Epistola lx.

† In the *Malade imaginaire*, *M. de Pourceaugnac*, and *L'Amour médecin*.

hended and enjoyed by his audience; for the faithfulness of such delineations is understood by the public only after it has been already recognized by the profession (97).

But modern physiology found expression at last in an institution not connected with the Paris Faculty. The Museum of Natural History in the Garden of Plants was founded, in 1635, as a medium of independent research and instruction; and in 1673 it was provided with a chair of anatomy, especially "for the propagation of new discoveries." This chair was occupied by Pierre Dionis, who lectured with great success for a series of years on *The Anatomy of Man, according to the circulation of the blood and the latest discoveries.* These lectures were afterward published in book form,* and, like the rest of Dionis' works, in the French language. Their dress, as well as their substance, was therefore in modern style; although an edition, published at Geneva in 1696, underwent beforehand a translation into Latin. Dionis does not originate any new doctrine on this subject, but he presents the experimental evidence in favor of the circulation, which he has himself verified. He recommends, as especially convincing and easy of performance, the ligature and puncture of the crural artery and vein. "This experiment," he says, "which may be done on a variety of animals, will satisfy you that the blood is transported by the arteries from the heart to the extremities, and that it is returned by the veins from the extremities to the heart."

* Nouvelle Anatomie de l'Homme, suivant la circulation du sang and les dernières Découvertes, Démontrée au Jardin Royal par Mr. Dionis, premier Chirurgien de feuë Madame la Dauphine, &c., Paris, 1690.

CHAPTER X.

VISIBLE PROOF OF THE CIRCULATION.

It appears, from the foregoing, that the question of a peripheral anastomosis between arteries and veins was a difficulty for both the friends and the enemies of the circulation. Many of its friends denied the existence of a direct anastomosis, and believed that the blood passed by filtration through the parenchyma of the organs. Its enemies held that so abundant a transit could only take place by vascular continuity, and they declared that such continuity had never received a practical demonstration. But this demonstration was at last accomplished.

The first to see the blood passing through the capillary vessels, from the arteries to the veins, was Marcello Malpighi, professor of medicine in the university of Bologna. In 1661 Malpighi was engaged in investigating the structure of the internal organs; and among his most valuable results were those obtained from the study of the lungs. They are embraced in two letters, *De Pulmonibus*, written, the same year, to his friend and benefactor Borelli, mathematical professor in the university of Pisa.*

In the first letter he informs Borelli of the success which has attended his researches on the lung tissue. These organs had been regarded as consisting, in addition to the bronchial tubes and bloodvessels, of a fleshy

* Marcelli Malpighii Opera Omnia. Londini, 1686, tom. ii., p. 133.

"parenchyma;" that is, of a semi-solid material, derived from sanguineous exudation, and not anatomically different from that of the liver or the spleen. But Malpighi found the whole of the pulmonary substance, attached to the bronchial tubes, to be "an aggregation of the finest and most delicate membranes, forming, by their extensions and sinuosities, innumerable rounded vesicles, like the cells of a honeycomb with their thin wax partitions." He discovered this structure by inflating the lungs, taken fresh from the recently killed animal, and observing with his magnifier (98) the distended vesicles on its surface: or still better, by first making the lung exsanguine with a watery injection, expelling the superfluous moisture by compression, then inflating the organ and drying it rapidly; when it became throughout so colorless and transparent that its vesicular texture could be seen both on the surface and internally. The repeated bifurcation of the bronchial tubes was also finely shown in such a preparation; and if the pulmonary artery, or one of its main divisions, were previously inflated and tied, its branches could be traced to their finest ramifications. An injection with mercury made these ramifications still more perceptible.

But the experimenter could not succeed in finding the actual termination of the pulmonary bloodvessels; and he gives a striking picture of the difficulties met with by a pioneer in such matters. "Whether these vessels have a mutual anastomosis, either in the follicles or elsewhere, by which the blood gets to the vein through a continuous channel, or whether they open into the pulmonary substance, is an enigma which, so far, distracts my mind; though, to solve it, I have made many and many attempts, quite unsuccessfully, with air and various colored liquids. After injecting ink with a syringe by the pulmonary artery, I have often seen it escape at several points; a very little compression will make it exude from the investing membrane and even collect in the interstices, though the greater part comes out, mixed with blood, by the pulmonary vein, and, what is more surprising, by the trachea, frothy, diluted, and pale-looking. The same thing happens with a mercurial injection. When the pulmonary artery is filled, the mercury penetrates to its extreme bifurcations; and if they are subjected to the least pressure, it escapes from the investing membrane, sometimes making its way into the interstices, and nearly the whole of it collecting there. These experiments do not give us the natural pathway of the blood; because the injected liquid makes for itself a variety of channels, not followed in the normal condition, from the mechanical disturbance of the parts and the unnatural constitution of the liquids."

In the second letter Malpighi has a more important communication to make. He has found that by using the lung of the *frog*, owing to its simplicity and transparency of texture, he can perceive many details which had before escaped him; and he says that by this means he "has had the good fortune to see such things" that he may well use in regard to them the expression of Homer:

"Magnum certum opus oculis video."

He opens the abdomen of the frog and allows the lung to protrude; when he can see in it the arrangement of the pulmonary membrane, with its internal prolongations and partitions, the interior cavities, and the arterial and venous ramifications. But beside these particulars relating to the structure of the part, microscopic observation shows something still more remarkable. "For while the heart is pulsating, the opposite motion of the blood may be seen in the vessels, so that the *circulation of the blood is evidently exhibited;* and it may be perceived even better in the mesentery and in other larger veins in the abdomen." He sees the blood coming into a follicle by the arterial branch, then bursting out, as in an overflow, into a multiplicity of tortuous channels, spreading all over the follicle, and then, at the partitions and angles, reaching the little branches of the vein which take it up.

He not only sees, in this way, the peripheral movement of the blood, but he also sees that it takes place through a network of new vessels, which are neither arteries nor veins; that is, he discovers the existence and character of the *capillary plexus.* "For such," he says, "is the divarication of these little vessels, coming in each direction from the vein and the artery, that the order in which the vessel ramifies is no longer preserved, but it appears like a network interwoven from the offshoots of both." Finally, he recommends, as the best method of observation, to lay the protruded frog's lung on a glass plate illuminated from below through a tube, and then to examine it "with a microscope of two lenses," when the whole distribution of the vessels and the movement of the blood will be visible; and by changing the intensity of the light, and similar contrivances which may be varied at will, he can bring into view still other things "which escape description by the pen." It may be readily conceded that the observer who first witnessed the capillary circulation in a living animal might consider himself as inadequate to its complete description.

From that time the batrachians did good service as subjects for microscopic observation. In 1684 Mr. William Molyneux, founder of the Dublin Royal Society, exhibited the circulation in the lung of the water newt. "In the body of this Animal there are two long Sacculi Aërei, on which the bloodvessels are curiously Ramified, to these bloodvessels applying a Microscope he showed the Circulation of the blood ad Oculum, as plainly as water running in a River, and more rapidly than any common Stream." *

The microscope employed by Molyneux was, no doubt, provided with the improved eye-piece invented by Divini in 1668. Instead of one double-convex lens, this eye-piece was composed of two plano-convex lenses so placed as to touch each other at the middle of their convex surface; and it enabled the instrument to "show the objects flat, and not crooked."† But it could hardly have been adapted to very high magnifying powers, and probably exhibited the motion of the blood as a glimmering current, without showing its minuter details.

Leeuwenhoek's microscope, with which he made so many discoveries, was a small glass globule, supported between two perforated silver plates. It was an instrument of imperfect definition, and not at all achromatic, but of very high magnifying power; and with it Leeuwenhoek had already, in 1674, discovered the red globules of the blood. He afterward applied it to

* Philosophical Transactions, vol. xv., Oxford, 1686, p. 1236.

† Philosophical Transactions for the year 1668, vol. iii., p. 842.

the circulation in the tail of the tadpole, where he could distinguish the globules following each other, in the smallest vessels, in single file, and sometimes even compressed or distorted in passing the narrowest part of the channel.

"The motion of the Blood," he says, "in these Tadpoles exceeds all the rest of small Animals and Fish, I have seen; nay, this pleasure has oftentimes been so recreating to me, that I do not believe that all the pleasure of Fountains or Waterworks, either natural or made by Art, could have pleased my sight so well."

"And now at last I spied a small artery, that notwithstanding it is so small that, I judge, but one small red globule of blood could pass through it;" . . . . "Yet what was most remarkable was, to see the manifold small arteries, that came forth from the great one, and which were spread into several branches, and turning came into one again, and were reunited, that at last they did powr out the blood again into the great vein; this last was a sight that would amaze any eye, that was greedy of knowledge." *

Finally, the vascular communication was also studied by means of *injections.* This method, which Malpighi had found unsatisfactory, seems to have been first successfully employed by Blancard, a medical practitioner of Amsterdam, in 1676, to demonstrate the terminal connection between arteries and veins. He used a wax injection, differently colored for different orders of vessels, a description of which is

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* Philosophical Transactions for January, 1700, vol. xxii., London, 1702, p. 447.

given in his treatise on anatomy,* published some years afterward. "You can obtain," he says, "a remarkable view of the capillary bloodvessels distributed through all parts of the body by filling them with wax and red lead or other coloring matter. To show, for example, the minute vessels of the lungs; the organs having been first freed from blood by a watery injection, and the moisture discharged by pressure, the artery is to be filled, by a syringe, with liquid wax and red lead. The vein may then be filled with black wax, the bronchial artery with green, and the trachea with white. The membranes and vesicles are then allowed to putrefy, and treated with cold water till the putrid matter is washed away. All the little branches of the arteries and veins, as well as those of the trachea, will then appear in the form of arborizations."

But the great master in the art of vascular injections was Frederick Ruysch, professor of Anatomy and Medicine at Amsterdam for the extraordinary period of sixty-two years; namely, from 1666 to 1728. His indefatigable industry and rare skill in anatomical preparations produced a cabinet of specimens which was celebrated throughout Europe, and which he catalogued in a series of illustrated publications. His preparations were remarkable for their neatness, permanency, brilliancy of color, and fineness of injection; but they were intended, for the most part, as cabinet specimens, to be viewed by the unaided eye or with a single loup. They especially illustrated the different forms of terminal ramification of arteries and veins in

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* Stephani Blancardi Anatomia Reformata, Lugd. Bat., 1695, De Balsamatione nova Methodus.

This work first appeared in 1687.

different organs; the most important feature, according to Ruysch, for determining the special secretory or nutritive action of a gland or tissue. Although it does not appear, therefore, that they had a direct bearing on the question of capillary communication, they exerted an important influence in turning the attention of anatomists in that direction. The success attained by Ruysch in the production of injected preparations showed the value and capabilities of this method, for investigating the vascular distribution throughout the body; and it was afterward applied to vessels of smaller calibre, the fineness of the injection keeping pace with gradual improvements in the microscope, until the mechanism of the capillary circulation, with all its varieties in different parts, was permanently demonstrated to the eye.

APPENDIX.

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(1)

THE following passages, among many which might be cited, will serve to illustrate the extent and variety of Aristotle's information:

The *cetacea* and the *selachia* (cartilaginous fishes) are both viviparous; but of these the selachia begin by the internal formation of an egg.—*Opera Omnia*, Vol. iii., p. 5.

Sponges are ranked among the animals, and are credited with a certain kind of sensibility.—*Ibid.*, p. 7.

The *elephant's trunk* is an elongated nose, which serves the purposes of a hand.—*Ibid.*, p. 10.

The brain is covered by *two membranes;* the outer one, in contact with the skull, stronger, the inner one more delicate.—*Ibid.*, p. 13.

In man, the heart is inclined toward the left; in other animals it is in the median line of the chest.—*Ibid.*, p. 15.

In some animals, as the fox, wolf, polecat, and weasel, the *penis is bony.*—*Ibid.*, p. 21.

In the ox and the horse, there is *a bone in the heart.*—*Ibid.*, p. 30.

The *gall-bladder is wanting* in the stag, the fallow-deer, the horse, the ass, the elephant, the seal, the dolphin, and some of the mouse family.—*Opera Omnia*, Vol. iii., p. 30.

There is sometimes *transposition of the abdominal organs*, so that the spleen is on the right side and the liver on the left. But these cases are regarded as monstrosities.—*Ibid.*, p. 31.

Another kind of fibres are those produced in the blood (fibrine). The blood *no longer coagulates* if this substance be taken out of it. Otherwise it coagulates. —*Ibid.*, p. 44.

In all animals provided with bones, the *spinal column* is the central or fundamental part (ἀρχὴ) of the skeleton.—*Ibid.*, p. 44.

The bones die (sphacelate) *if deprived of their periosteum.*—*Ibid.*, p. 49.

Fat *does not putrefy.* Blood, on the other hand, as well as the tissues containing it, putrefies readily.—*Ibid.*, p. 52.

The marrow of the bones *in young animals* is sanguineous throughout; in the *older* it becomes fatty or lardaceous, according to the species of animal.—*Ibid.*, p. 53.

The *mammæ* are found in all the completely viviparous animals; such as man, the horse, and cetacea, namely, the dolphin, the seal, the whale, etc. All of these have mammæ and milk.—*Ibid.*, p. 53.

The male, both of man and other animals, ordinarily has no milk, *though the contrary sometimes happens.* Occasionally, in man, at the age of puberty, a little milk may be expressed from the glands, and sometimes in considerable quantity.—*Ibid.*, p. 53.

The natural time for conception, in women, is that immediately after the katamenia; and women who have no katamenia are generally sterile. *But there are some exceptions to this rule.—Opera Omnia*, Vol. iii., p. 136.

The right kidney, in all animals provided with these organs, is *placed higher than the left.* Owing to this position it lies in contact with the liver, which is also situated on the right side.—*Ibid.*, p. 267.

There is a provision against interference with respiration from the ingestion of food. Air-breathing animals *never inspire and swallow at the same time.* Should they do so, the food, whether solid or liquid, gets into the trachea, and so down to the lung, causing strangulation. The trachea lies in front of the œsophagus, through which the food passes to the stomach; and in the quadrupeds having an abundance of blood (mammalians) it is provided with the epiglottis, which serves as a sort of cover. In birds and oviparous quadrupeds (reptiles), where there is no epiglottis, *the same thing is accomplished by an act of constriction.* At the time of deglutition, in these animals, the trachea is constricted; in the former, it is covered by the epiglottis. After the passage of the food the epiglottis is lifted, or the trachea opened, and the breath is inhaled.—*Ibid.*, p. 544.

In diseases which produce induration of the lung, either by morbid growths, exudations, or excess of unnatural heat, as in fevers, respiration is accelerated, *because the expansion and collapse of the lung are limited in extent.—Ibid.*, p. 549.

(2)

Ἡ δὲ καρδία, διὰ τὸ τῶν φλεβῶν ἀρχὴ εἶναι καὶ *ἔχειν ἐν αυτῇ τὴν δύναμιν τὴν δημιουργοῦσαν τὸ αἷμα πρώτην, εὔλογον, ἐξ οἵας δέχεται τροφῆς, ἐκ τοιαύτης συνεστάναι καὶ αὐτήν.*

"The heart, on the other hand, being the origin of the blood-vessels, and containing within itself the primal force for the formation of the blood, consists, no doubt, of materials drawn directly from the nutriment."—*Aristotle Opera Omnia*, Vol. iii., p. 230.

Καρδία *μὲν οὖν καὶ ἧπαρ πᾶσιν ἀναγκαῖα τοῖς ζῴοις, ἡ μὲν διὰ τὴν τῆς θερμότητος ἀρχὴν (δεῖ γὰρ εἶναί τινα οἷον ἑστίαν, ἐν ᾗ κείσεται τῆς φύσεως τὸ ζωπυροῦν, καὶ τοῦτο εὐφύλακτον, ὥσπερ ἀκρόπολις οὖσα τοῦ σώματος), τὸ δ' ἧπαρ τῆς πέψεως χάριν.*

"The heart and the liver, accordingly, are indispensable organs in all animals;—the former as the source of heat, since there must be a focus or fire-place of some kind, where the embers of nature are kept alive—well protected and, as it were, the citadel of the body; and the liver to aid in digestion."—*Ibid.*, p. 265.

(3)

Ἔχει *δὲ τοῦτον τὸν τρόπον ἡ τῶν φλεβῶν φύσις· δύο φλέβες εἰσὶν ἐν τῷ θώρακι κατὰ τὴν ῥάχιν ἐντός· ἔστι δὲ κειμένη αὐτῶν ἡ μὲν μείζων ἐν τοῖς ἔμπροσθεν, ἡ δ' ἐλάττων ὄπισθεν ταύτης, καὶ ἡ μὲν μείζων ἐν τοῖς δεξιοῖς μᾶλλον, ἡ δ' ἐλάττων ἐν τοῖς ἀριστεροῖς, ἣν καλοῦσί τινες ἀορτὴν ἐκ τοῦ τεθεᾶσθαι καὶ ἐν τοῖς τεθνεῶσι τὸ νευρῶδες αὐτῆς μόριον.*

"The arrangement of the vascular system is as follows:—There are two blood-vessels within the thorax, along the spinal column. The larger of them is toward the front, the smaller behind. The larger is rather on the right side; the smaller, sometimes called the 'aorta,' because of its fibrous texture, perceptible even in the dead body, is on the left."—*Aristotle. Opera Omnia*, Vol. iii., p. 40.

Τὸν δ' αὐτὸν τρόπον καὶ τὰ τῆς ἐλάττονος φλεβὸς, καλουμένης δ' ἀορτῆς, ἔσχισται μέρη, συμπαρακολουθοῦντα τοῖς τῆς μεγάλης, πλὴν ἐλάττους οἱ πόροι καὶ τὰ φλέβια πολλῷ ἐλάττω ταῦτ' ἐστὶ τῶν τῆς μεγάλης φλεβός.

"The divisions of the smaller blood-vessel, called the aorta, are distributed in the same way—running in company with and alongside those of the larger; only their channels and branchlets are much smaller than those of the great blood-vessel."—*Ibid.*, p. 42.

Καὶ ἡ καλουμένη ἀορτὴ νευρώδης ἐστὶ φλέψ, τὰ μὲν τελευταῖα καὶ παντελῶς αὐτῆς· ἄκοιλα γάρ ἐστι, καὶ τάσιν ἔχει τοιαύτην, οἵαν περ τὰ νεῦρα, ᾗ τελευτᾷ πρὸς τὰς καμπὰς τῶν ὀστῶν.

"The so-called aorta is a blood-vessel of fibrous texture, its extreme branches being entirely so; for they have no cavity, and resemble in consistency the sinews where they terminate at the bony articulations."—*Ibid.*, p. 43.

Ἑπόμενον δ' ἂν εἴη περὶ τῶν φλεβῶν εἰπεῖν, τῆς τε μεγάλης καὶ τῆς ἀορτῆς· αὗται γὰρ ἐκ τῆς καρδίας πρῶται δέχονται τὸ αἷμα, αἱ δὲ λοιπαὶ τούτων ἀποφυάδες εἰσίν. Ὅτι μὲν οὖν τοῦ αἵματος χάριν εἰσὶ, πρότερον εἴρηται· τό τε γὰρ ὑγρὸν ἅπαν ἀγγείον δεῖται, καὶ τὸ φλεβῶν γένος ἀγγεῖον, τὸ δ' αἷμα ἐν ταύταις· διότι δὲ δύο καὶ ἀπὸ μιᾶς ἀρχῆς καθ' ἅπαν τὸ σῶμα διατείνουσι, λέγωμεν. Τοῦ μὲν οὖν εἰς μίαν ἀρχὴν συντελεῖν καὶ ἀπὸ μιᾶς αἴτιον τὸ μίαν ἔχειν πάντα τὴν αἰσθητικὴν ψυχὴν ἐνεργείᾳ, ὥστε καὶ τὸ μόριον ἓν τὸ ταύτην ἔχον πρώτως, ἐν μὲν τοῖς ἐναίμοις κατὰ δὺναμιν καὶ κατ' ἐνέργειαν, τῶν δ' ἀναίμων ἐνίοις κατ' ἐνέργειαν μόνον· διὸ καὶ τὴν τοῦ θερμοῦ ἀρχὴν ἀναγκαῖον ἐν τῷ αὐτῷ τόπῳ εἶναι· αὕτη δ' ἐστὶν αἰτία καὶ τῷ αἵματι τῆς ὑγρότητος καὶ τῆς θερμότητος. Διὰ μὲν οὖν τὸ ἐν ἑνὶ εἶναι μορίῳ τὴν αἰσθητικὴν ἀρχὴν καὶ τὴν τῆς θερμότητος καὶ ἡ τοῦ αἵματος ἀπὸ μιᾶς ἐστιν ἀρχῆς, διὰ δὲ τὴν τοῦ αἵματος ἑνότητα καὶ ἡ τῶν φλεβῶν ἀπὸ μιᾶς· δύο δ' εἰσι διὰ τὸ τὰ σώματα εἶναι διμερῆ τῶν ἐναίμων καὶ πορευτικῶν· ἐν πᾶσι γὰρ τούτοις διώρισται τὸ ἔμπροσθεν καὶ τὸ ὄπισθεν, καὶ τὸ δεξιὸν καὶ τὸ ἀριστερὸν, καὶ τὸ ἄνω καὶ τὸ κάτω. Ὅσῳ δὲ τιμιώτερον καὶ ἡγεμονικώτερον τὸ ἔμπροσθεν τοῦ ὄπισθεν, τοσούτῳ καὶ ἡ μεγάλη φλὲψ τῆς ἀορτῆς· ἡ μὲν γὰρ ἐν τοῖς ἔμπροσθεν, ἡ δ' ἐν τοῖς ὄπισθεν κεῖται, καὶ τὴν μὲν ἅπαντ' ἔχει τὰ ἔναιμα φανερῶς, τὴν δ' ἔνια μὲν ἀμυδρῶς, ἔνια δ' ἀφανῶς. Τοῦ δ' εἰς τὸ πᾶν διαδεδόσθαι τὸ σῶμα τὰς φλέβας αἴτιον τὸ παντὸς εἶναι τοῦ σώματος ὕλην τὸ αἷμα, τοῖς δ' ἀναίμοις τὸ ἀνάλογον, ταῦτα δ' ἐν φλεβὶ καὶ τῷ ἀνάλογον κεῖσθαι.

"We now come to speak of the blood-vessels, both the great one (vena cava) and the aorta. These first receive the blood from the heart, and the other blood-vessels are offshoots from them. They exist, as we have said, for the sake of the blood. For every liquid must have a containing receptacle, and the vascular system is a receptacle in which the blood is contained. We have next to consider why there are two blood-vessels, coming from one source, and distributed through the entire body. That they originate at a single starting-point is because the principle of life and sensibility is, in all animals, actually a single one, and is therefore primarily located in a single organ;—both potentially and actually single in animals provided with blood, and actually single in all. Wherefore the prime source or principle of heat must have the same location, being itself the cause of warmth and fluidity in the blood. The blood, therefore, is derived from a single source, because that of sensibility and heat is in a single organ; and the blood-vessels start from one origin because *the blood itself is single*. They are two in number because the body is divided into different parts and regions; at least, in animals having blood and limbs, where there is a distinction between front and back, right and left, and upper and under parts. As the front part is more important and more fully developed than the back, so is the great blood-vessel (vena cava) more than the aorta. The former is situated in front, the latter behind; and the former, in animals provided with blood, is always conspicuous, while the latter is sometimes obscure or imperceptible. The reason, furthermore, why the blood-vessels extend everywhere throughout the body, is that they contain the blood, which is the nutritive material for the whole body;—both blood and blood-vessels being represented, in the exsanguine animals, by other analogous parts."—*Aristotle. Opera Omnia*, Vol. iii., p. 261.

(4)

Μέσον γὰρ τὸ τῆς καρδίας ἐστὶ σῶμα, πυκνον καὶ κοῖλον πεφυκὸς, ἔτι δὲ πλῆρες αἵματος, ὡς τῶν φλεβῶν ἐντεῦθεν ἠργμένων, κοῖλον μὲν πρὸς τὴν ὑποδοχὴν τοῦ αἵματος, πυκνὸν δὲ πρὸς τὸ φυλάσσειν τὴν ἀρχὴν τῆς θερμότητος· ἐν ταύτῃ γὰρ μόνῃ τῶν σπλάγχνων καὶ τοῦ σώματος αἷμα ἄνευ φλεβῶν ἐστι, τῶν δ' ἄλλων μορίων ἕκαστον ἐν ταῖς φλεψὶν ἔχει τὸ αἷμα, καὶ τοῦτ' εὐλόγως· ἐκ τῆς καρδίας γὰρ ἐποχετεύεται καὶ εἰς τὰς φλέβας, εἰς δὲ τὴν καρδίαν οὐκ ἄλλοθεν· αὕτη γάρ ἐστιν ἀρχὴ καὶ πηγὴ τοῦ αἵματος, ἢ ὑποδοχὴ πρώτη.

Ibid., p. 258.

(5)

Ἐπεὶ δ' εἴρηται πρότερον ὅτι τὸ ζῆν καὶ ἡ τῆς ψυχῆς ἕξις μετὰ θερμότητός τινός ἐστιν· οὐδὲ γὰρ ἡ πέψις, δι' ἧς ἡ τροφὴ γίνεται τοῖς ζῴοις, οὔτ' ἄνευ ψυχῆς, οὔτ' ἄνευ θερμότητός ἐστιν· πυρὶ γὰρ ἐργάζεται πάντα· διόπερ ἐν ᾧ πρώτῳ τόπῳ τοῦ σώματος καὶ ἐν ᾧ πρώτῳ τοῦ τόπου τούτου μορίῳ τὴν ἀρχὴν ἀναγκαῖον εἶναι τὴν τοιαύτην, ἐνταῦθα καὶ τὴν πρώτην τὴν θρεπτικὴν ψυχὴν ἀναγκαῖον ὑπάρχειν. * * * Τοῖς μὲν οὖν ἀναίμοις ἀνώνυμον, τοῖς δ' ἐναίμοις ἡ καρδία τοῦτο τὸ μόριόν ἐστιν· ἡ τροφὴ μὲν γὰρ ἐξ ἧς ἤδη γίνεται τὰ μόρια τοῖς ζῴοις, ἡ τοῦ αἵματος φύσις ἐστίν· τοῦ δ' αἵματος καὶ τῶν φλεβῶν τὴν αὐτὴν ἀρχὴν ἀναγκαῖον εἶναι· θατέρου γὰρ ἕνεκα θάτερόν ἐστιν, ὡς ἀγγεῖον καὶ δεκτικόν· ἀρχὴ δὲ τῶν φλεβῶν ἡ καρδία τοῖς ἐναίμοις· οὐ γὰρ διὰ ταύτης, ἀλλ' ἐκ ταύτης ἠρτημέναι πᾶσαι τυγχανουσιν. Δῆλον δ' ἡμῖν τοῦτο ἐκ τῶν ἀνατομῶν. Τὰς μὲν οὖν ἄλλας δυνάμεις τῆς ψυχῆς ἀδύνατον ὑπάρχειν ἄνευ τῆς θρεπτικῆς (δι' ἣν δ' αἰτίαν, εἴρηται πρότερον ἐν τοῖς περὶ ψυχῆς), ταύτην δ' ἄνευ τοῦ φυσικοῦ πυρός· ἐν τούτῳ γὰρ ἡ φύσις ἐμπεπύρευκεν αὐτήν.

Aristotle. Opera Omnia, Vol. iii., p. 542.

(6)

Ταύτῃ δ' ἠκολούθηκε καὶ τῶν ἄλλων τῶν καλουμένων σπλάγχνων ἕκαστον· ἐκ τῆς αὐτῆς γὰρ ὕλης συνεστᾶσιν· αἱματικὴ γὰρ ἡ φύσις πάντων αὐτῶν διὰ τὸ τὴν θέσιν ἔχειν ἐπὶ πόροις φλεβικοῖς καὶ διαλήψεσιν. Καθάπερ οὖν ῥέοντος ὕδατος ἰλὺς, τἆλλα σπλάγχνα τῆς διὰ τῶν φλεβῶν ῥύσεως τοῦ αἵματος οἷον προχεύματά ἐστιν· ἡ δὲ καρδία, διὰ τὸ τῶν φλεβῶν ἀρχὴ εἶναι καὶ ἔχειν ἐν αὐτῇ τὴν δύναμιν τὴν δημιουργοῦσαν τὸ αἷμα πρώτην, εὔλογον, ἐξ οἵας δέχεται τροφῆς, ἐκ τοιαύτης συνεστάναι καὶ αὐτήν.

"The rest of the so-called viscera are subsequent in formation to this one (the heart), and are all produced from one and the same material. They derive their growth and constitution from the blood, owing to their position at the passages and interspaces of the blood-vessels. For as mud or clay is deposited from running water, so these viscera are, as it were, deposits from the flux of the blood through the (walls of the)* blood-vessels. The heart, on the other hand, being the origin of the blood-vessels, and containing within itself the primal force for the formation of the blood, consists, no doubt, of materials drawn directly from the nutriment."—*Ibid.*, p. 230.

* The word διὰ means "through," in the sense of penetration.

Πῶς μὲν οὖν τρέφεται τὰ ζῷα, καὶ ἐκ τίνος, καὶ τίνα τρόπον ἀναλαμβάνουσιν ἐκ τῆς κοιλίας, ἐν τοῖς περὶ γενέσεως λόγοις μᾶλλον ἁρμόζει σκοπεῖν καὶ λέγειν· συνισταμένων δὲ τῶν μορίων ἐκ τοῦ αἵματος, καθάπερ εἴπομεν, εὐλόγως ἡ τῶν φλεβῶν ῥύσις διὰ παντὸς τοῦ σώματος πέφυκεν· δεῖ γὰρ καὶ τὸ αἷμα διὰ παντὸς καὶ παρὰ πᾶν εἶναι, εἴπερ τῶν μορίων ἕκαστον ἐκ τούτου συνέστηκεν. Ἔοικε δ' ὥσπερ ἔν τε τοῖς κήποις αἱ ὑδραγωγίαι κατασκευάζονται ἀπὸ μιᾶς ἀρχῆς καὶ πηγῆς εἰς πολλοὺς ὀχετοὺς καὶ ἄλλους ἀεὶ πρὸς τὸ πάντῃ μεταδιδόναι, καὶ ἐν ταῖς οἰκοδομίαις παρὰ πᾶσαν τὴν τῶν θεμελίων ὑπογραφὴν λίθοι παραβέβληνται διὰ τὸ τὰ μὲν κηπευόμενα φύεσθαι ἐκ τοῦ ὕδατος, τοὺς δὲ θεμελίους ἐκ τῶν λίθων οἰκοδομεῖσθαι, τὸν αὐτὸν τρόπον καὶ ἡ φύσις τὸ αἷμα διὰ παντὸς ὠχέτευκε τοῦ σώματος, ἐπειδὴ παντὸς ὕλη πέφυκε τοῦτο.

"How the nutrition of animals is accomplished, and through what organs and in what way they take up their nourishment from the alimentary canal, may be more appropriately discussed elsewhere. Nevertheless, since the substance of the organs is supplied, as we have said, from the blood, the flux,* or exuda-

* The word ῥύσις, or ῥεῦσις, translated "flux" in these two passages, does not mean a flowing, as of the current in a river, but a running or discharge of liquid from a membranous surface. Other medical terms derived from ῥέω, to flow, are κατάῤῥοος, catarrh, a flux or discharge downward, as in nasal catarrh; διάῤῥοια, diarrhœa, a discharge through the intestine; and ῥεῦμα, rheum, the substance or liquid matter discharged. This distinction is of some importance, since otherwise Aristotle might be supposed to speak of the blood as flowing in a current within the blood-vessels;—an idea which was never present to his mind.

tion, of the blood-vessels is established by nature throughout the body. For the blood, if it be indeed the constituent material of all the organs, must be everywhere present and permeate every part. As, in the irrigation of gardens, sluices are constructed to lead from a single fountain-head into many different waterways for general distribution; and as, in building houses, stones are brought and laid everywhere alongside the trace of the foundations—in order that the garden crops may be nourished with water, and the foundation walls be built of stone—so nature has distributed the blood throughout the body, it being the material from which every part is formed."—*Aristotle. Opera Omnia*, Vol. iii., p. 261.

(7)

Ἡ *μὲν γὰρ πρώτη φανερὰ τοῖς ζῴοις λειτουγία διὰ τοῦ στόματος οὖσα καὶ τῶν ἐν τούτῳ μορίων, ὅσων ἡ τροφὴ δεῖται διαιρέσεως· ἀλλ' αὕτη μὲν οὐδεμιᾶς αἰτία πέψεως, ἀλλ' εὐπεψίας μᾶλλον· ἡ γὰρ εἰς μικρὰ διαίρεσις τῆς τροφῆς ῥᾴω ποιεῖ τῷ θερμῷ τὴν ἐργασίαν· ἡ δὲ τῆς ἄνω καὶ τῆς κάτω κοιλίας ἤδη μετὰ θερμότητος φυσικῆς ποιεῖται τὴν πέψιν.*

"The first of these operations, in animals whose food requires comminution, is that performed by the mouth and the organs therein situated. This does not itself produce any digestive effect, but serves rather to facilitate digestion. For the minute division of the food makes the action of heat upon it more easy; and the stomach and bowels then accomplish its digestion by their own natural warmth."—*Ibid.*, p. 234.

(8)

Ἐπεὶ δ᾽ ἐν τῇ ἄνω μὲν κοιλίᾳ κατὰ τὴν πρώτην εἴσοδον τῆς τροφῆς νεαρὰν ἀναγκαῖον εἶναι τὴν τροφὴν, κάτω δὲ προϊοῦσαν κοπρώδη καὶ ἐξικμασμένην, ἀναγκαῖον εἶναί τι καὶ τὸ μεταξὺ, ἐν ᾧ μεταβάλλει καὶ οὔτ᾽ ἔτι πρόσφατος, οὔτ᾽ ἤδη κόπρος· διὰ τοῦτο πάντα τὰ τοιαῦτα ζῷα τὴν καλουμένην ἔχει νῆστιν καὶ ἐν τῷ μετὰ τὴν κοιλίαν ἐντέρῳ τῷ λεπτῷ· τοῦτο γὰρ μεταξὺ τῆς τ᾽ ἄνω, ἐν ᾗ τὸ ἄπεπτον, καὶ τῆς κάτω, ἐν ᾗ τὸ ἄχρηστον ἤδη περίττωμα.

"As the food at its first entrance in the stomach is in a recent condition, becoming exhausted and feculent farther down, there must be an intermediate place, in which its metamorphosis is going on, and where it is neither fresh food nor yet feces. For this, the above-mentioned animals have what is called the jejunum, in the narrow part of the intestine below the stomach; lying between the upper cavity, in which is the undigested food, and the lower, in which is the superfluous residue."—*Aristotle. Opera Omnia*, Vol. iii., p. 273.

(9)

Ὥσπερ δὲ καὶ τὸ στόμα τῆς ἀκατεργάστου τροφῆς πόρος ἐστὶ καὶ τὸ συνεχὲς αὐτῷ μόριον ὃ καλοῦσιν οἰσοφάγον, ὅσα τῶν ζῴων ἔχει τοῦτο τὸ μόριον, ἕως εἰς τὴν κοιλίαν, οὕτω καὶ ἄλλας ἀρχὰς δεῖ πλείους εἶναι, δι᾽ ὧν ἅπαν λήψεται τὸ σῶμα τὴν τροφὴν, ὥσπερ ἐκ φάτνης, ἐκ τῆς κοιλίας καὶ τῆς τῶν ἐντέρων φύσεως· τὰ μὲν γὰρ φυτὰ λαμβάνει τὴν τροφὴν κατειργασμένην ἐκ τῆς γῆς ταῖς ῥίζαις (διὸ καὶ περίττωμα οὐ γίνεται τοῖς φυτοῖς· τῇ γὰρ γῇ καὶ τῇ ἐν αὐτῇ θερμότητι χρῆται ὥσπερ κοιλίᾳ), τὰ δὲ ζῷα πάντα μὲν σχεδὸν, τὰ δὲ πορευτικὰ φανερῶς, οἷον γῆν ἐν αὑτοῖς ἔχει τὸ τῆς κοιλίας κύτος, ἐξ ἧς, ὥσπερ ἐκεῖνα ταῖς ῥίζαις, ταῦτα δεῖ τινι τὴν τροφὴν λαμβάνειν, ἕως τὸ τῆς ἐχομένης πέψεως λάβῃ τέλος.

Aristotle. Opera Omnia, Vol. iii., p. 234.

(10)

Τὸ δὲ καλούμενον μεσεντέριον ἔστι μὲν ὑμὴν, διατείνει δὲ συνεχὲς ἀπὸ τῆς τῶν ἐντέρων παρατάσεως εἰς τὴν φλέβα τὴν μεγάλην καὶ τὴν ἀορτὴν, πλῆρες ὂν φλεβῶν πολλῶν καὶ πυκνῶν, αἳ τείνουσιν ἀπὸ τῶν ἐντέρων εἴς τε τὴν μεγάλην φλέβα καὶ τὴν ἀορτήν. Τὴν μὲν οὖν γένεσιν ἐξ ἀνάγκης οὖσαν εὑρήσομεν ὁμοίως τοῖς ἄλλοις μορίοις· διὰ τίνα δ' αἰτίαν ὑπάρχει τοῖς ἐναίμοις, φανερόν ἐστιν ἐπισκοποῦσιν· ἐπεὶ γὰρ ἀναγκαῖον τὰ ζῷα τροφὴν λαμβάνειν θύραθεν, καὶ πάλιν ἐκ ταύτης γίνεσθαι τὴν ἐσχάτην τροφὴν, ἐξ ἧς ἤδη διαδίδοται εἰς τὰ μόρια (τοῦτο δὲ τοῖς μὲν ἀναίμοις ἀνώνυμον, τοῖς δ' ἐναίμοις αἷμα καλεῖται), δεῖ τι εἶναι δι' οὗ εἰς τὰς φλέβας ἐκ τῆς κοιλίας οἷον διὰ ῥιζῶν πορεύσεται ἡ τροφή. Τὰ μὲν οὖν φυτὰ τὰς ῥίζας ἔχει εἰς τὴν γῆν (ἐκεῖθεν γὰρ λαμβάνει τὴν τροφήν), τοῖς δὲ ζῴοις ἡ κοιλία καὶ ἡ τῶν ἐντέρων δύναμις γῆ ἐστιν, ἐξ ἧς δεῖ λαμβάνειν τὴν τροφήν· διόπερ ἡ τοῦ μεσεντερίου φύσις ἐστὶν, οἷον ῥίζας ἔχουσα τὰς δι' αὐτῆς φλέβας. *Ibid.*, p. 276.

(11)

Πρότερον δὲ τῇ θέσει ἡ ἀρτηρία κεῖται τοῦ οἰσοφάγου ἐν πᾶσι τοῖς ἔχουσιν αὐτήν· ἔχει δὲ ταύτην *πάντα ὅσα περ καὶ πλεύμονα ἔχει. Ἔστι δ' ἡ μὲν ἀρτηρία χονδρώδης τὴν φύσιν καὶ ὀλίγαιμος, πολλοῖς λεπτοῖς φλεβίοις περιεχομένη, κεῖται δ' ἐπὶ μὲν τὰ ἄνω πρὸς τὸ στόμα κατὰ τὴν ἐκ τῶν μυκτήρων σύντρησιν εἰς τὸ στόμα, ᾗ καὶ, ὅταν πίνοντες ἀνασπάσωσί τι τοῦ ποτοῦ, χωρεῖ ἐκ τοῦ στόματος διὰ τῶν μυκτήρων ἔξω. Μεταξὺ δ' ἔχει τῶν τρήσεων τὴν ἐπιγλωττίδα καλουμένην, ἐπιπτύσσεσθαι δυναμένην ἐπὶ τὸ τῆς ἀρτηρίας τρῆμα τὸ εἰς τὸ στόμα τεῖνον· ταύτῃ δὲ τὸ πέρας συνήρτηται τῆς γλώττης. Ἐπὶ δὲ θάτερα καθήκει εἰς τὸ μεταξὺ τοῦ πλεύμονος, εἶτ' ἀπὸ τούτου σχίζεται εἰς ἑκάτερον τῶν μερῶν τοῦ πλεύμονος.* * * * *Φυσωμένης δὲ τῆς ἀρτηρίας, διαδίδωσιν εἰς τὰ κοῖλα μέρη τοῦ πλεύμονος τὸ πνεῦμα. Ταῦτα δὲ διαφύσεις ἔχει χονδρώδεις εἰς ὀξὺ συνεκούσας· ἐκ δὲ τῶν διαφύσεων τρήματα διὰ παντός ἐστι τοῦ πλεύμονος, ἀεὶ ἐκ μειζόνων εἰς ἐλάττω διαδιδόμενα.* * * * *Ἡ μὲν οὖν ἀρτηρία τοῦτον ἔχει τὸν τρόπον, καὶ δέχεται μόνον τὸ πνεῦμα καὶ ἀφίησιν, ἄλλο δ' οὐθὲν οὔτε ξηρὸν, οὔθ' ὑγρὸν, ἢ πόνον παρέχει, ἕως ἂν ἐκβήξῃ τὸ κατελθόν.*

Aristotle. Opera Omnia, Vol. iii., p. 14.

(12)

Καὶ ἐς τὴν ἀρτηρίαν κατεῤῥύη τοιοῦτον, οἷον ἐπισχεῖν διαλεγόμενον, καὶ ἀσθμαινεῖν ἐν τῷ διαλέγεσθαι ὁμοίως κυναγχικῷ βραγχώδει.

"And there was such a flux into the trachea that in talking he had stoppage of the voice and dyspnœa, like a man with suffocative bronchitis."—Περὶ ἐπιδημιῶν, vii. 9. *Œuvres d'Hippocrate*, Littré's edition, Paris, 1839–61, Vol. v., p. 380.

(13)

Φέρουσι δὲ καὶ εἰς τὸν πλεύμονα πόροι ἀπὸ τῆς καρδίας, καὶ σχίζονται τὸν αὐτὸν τρόπον ὅνπερ ἡ ἀρτηρία, κατὰ πάντα τὸν πλεύμονα παρακολουθοῦντες τοῖς ἀπὸ τῆς ἀρτηρίας· ἐπάνω δ' εἰσὶν οἱ ἀπὸ τῆς καρδίας πόροι· πόρος δ' οὐθεὶς ἔστι κοινὸς, ἀλλὰ διὰ τὴν σύναψιν δέχονται τὸ πνεῦμα καὶ τῇ καρδίᾳ διαπέμπουσιν· φέρει γὰρ ὁ μὲν εἰς τὸ δεξιὸν κοῖλον τῶν πόρων, ὁ δ' εἰς τὸ ἀριστερόν. Περὶ δὲ τῆς φλεβὸς τῆς μεγάλης καὶ τῆς ἀορτῆς καθ' αὑτὰς κοινῇ περὶ ἀμφοτέρων ἐροῦμεν ὕστερον.

Aristotle. Opera Omnia, Vol. iii , p. 15.

(14)

Ἡ δὲ συμβαίνουσα σφύξις τῆς καρδίας, ἣν ἀεὶ φαίνεται ποιουμένη συνεχῶς, ὁμοία φύμασίν ἐστιν, ἣν ποιοῦνται κίνησιν μετ' ἀλγηδόνος διὰ τὸ παρὰ φύσιν εἶναι τῷ αἵματι τὴν μεταβολήν· γίνεται δὲ μέχρι οὗ ἂν πυωθῇ πεφθέν. Ἔστι δ' ὅμοιον ζέσει τοῦτο τὸ πάθος· ἡ γὰρ ζέσις γίνεται πνευματουμένου τοῦ ὑγροῦ ὑπὸ τοῦ θερμοῦ· αἴρεται γὰρ διὰ τὸ πλείω γίνεσθαι τὸν ὄγκον. Παῦλα δ' ἐν μὲν τοῖς φύμασιν, ἐὰν μὴ διαπνεύσῃ, παχυτέρου γινομένου τοῦ ὑγροῦ, σῆψις, τῇ δὲ ζέσει ἡ ἔκπτωσις διὰ τῶν ὁριζόντων. Ἐν δὲ τῇ καρδίᾳ ἡ τοῦ ἀεὶ προσιόντος ἐκ τῆς τροφῆς ὑγροῦ διὰ τῆς θερμότητος ὄγκωσις ποιεῖ σφυγμὸν, αἰρομένη πρὸς τὸν ἔσχατον χιτῶνα τῆς καρδίας. Καὶ τοῦτ' ἀεὶ γίνεται συνεχῶς· ἐπιρρεῖ γὰρ ἀεὶ τὸ ὑγρὸν συνεχῶς, ἐξ οὗ γίνεται ἡ τοῦ αἵματος φύσις· πρῶτον γὰρ ἐν τῇ καρδίᾳ δημιουργεῖται. Δῆλον δ' ἐν τῇ γενέσει ἐξ ἀρχῆς· οὔπω γὰρ διωρισμένων τῶν φλεβῶν, φαίνεται ἔχουσα αἷμα. Καὶ διὰ τοῦτο σφύζει μᾶλλον τοῖς νεωτέροις τῶν πρεσβυτέρων· γίνεται γὰρ ἡ ἀναθυμίασις πλείων τοῖς νεωτέροις. Καὶ σφύζουσιν αἱ φλέβες πᾶσαι, καὶ ἅμα ἀλλήλαις, διὰ τὸ ἠρτῆσθαι ἐκ τῆς καρδίας, κινεῖ δ' ἀεὶ, ὥστε κἀκεῖναι αἰεὶ, καὶ ἅμα ἀλλήλαις, ὅτε κινεῖ.—*Aristotle. Opera Omnia*, Vol. iii., p. 550.

(15)

Οἱ ἀναιροῦντες ὡς οὐ τὸ θερμὸν τὸ ἐργαζόμενον ἐν τοῖς σώμασιν, [ἢ] ὅτι μία τις φορὰ καὶ δύναμις ἡ τμητικὴ τοῦ πυρὸς, οὐ καλῶς λέγουσιν· οὐδὲ γὰρ ὅλα τοῖς ἀψύχοις ταὐτὸ ποιεῖ πᾶσιν, ἀλλὰ τὰ μὲν πυκνοῖ, τὰ δὲ μανοῖ καὶ τήκει, τὰ δὲ πήγνυσιν. Ἐν δὲ δὴ τοῖς ἐμψύχοις οὕτως ὑποληπτέον, ὥσπερ φύσεως πῦρ ζητοῦντα, καθάπερ τέχνης· καὶ γὰρ ἐν ταῖς τέχναις ἕτερον τὸ χρυσοχοϊκὸν καὶ τὸ χαλκευτικὸν καὶ τὸ τεκτονικὸν πῦρ ἀποτελεῖ, καὶ τὸ μαγειρικόν. Ἴσως δ' ἀληθέστερον ὅτι αἱ τέχναι· χρῶνται γὰρ ὥσπερ ὀργάνῳ μαλάττουσαι καὶ τήκουσαι καὶ ξηραίνουσαι, ἔνια δὲ καὶ ῥυθμίζουσαι. Τὸ αὐτὸ δὲ τοῦτο καὶ αἱ φύσεις· ὅθεν δὴ καὶ πρὸς ἄλληλα διαφοραί· διὸ γελοῖον πρὸς τὸ ἔξω κρίνειν· εἴτε γὰρ διακρῖνον, εἴτε λεπτῦνον, εἴθ' ὁτιδήποτ' ἐστὶ τὸ θερμαίνεσθαι καὶ πυροῦσθαι, διαφορὰν ἕξει τὰ ἔργα τοῖς χρωμένοις. Ἀλλ' αἱ μὲν τέχναι ὡς ὀργάνῳ χρῶνται, ἡ δὲ φύσις ἅμα καὶ ὡς ὕλῃ.

Ibid., p. 669.

(16)

Διὰ τί δὲ τὰ ἔχοντα δέχεται τὸν ἀέρα καὶ ἀναπνέουσι, καὶ μάλιστ' αὐτῶν ὅσα ἔχουσιν ἔναιμον, αἴτιον τοῦ μὲν ἀναπνεῖν ὁ πνεύμων σομφὸς ὢν καὶ συρίγγων πλήρης. Καὶ ἐναιμότατον δὴ μάλιστα τοῦτο τὸ μόριον τῶν καλουμένων σπλάγχνων.

Ὅσα δὴ ἔχει ἔναιμον αὐτὸ, ταχείας μὲν δεῖται τῆς καταψύξεως διὰ τὸ μικρὰν εἶναι τὴν ῥοπὴν τοῦ ψυχικοῦ πυρὸς, εἴσω δ' εἰσιέναι διὰ παντὸς διὰ τὸ πλῆθος τοῦ αἵματος καὶ τῆς θερμότητος. Ταῦτα δ' ἀμφότερα ὁ μὲν ἀὴρ δύναται ῥᾳδίως ποιεῖν· διὰ γὰρ τὸ λεπτὴν ἔχειν τὴν φύσιν διὰ παντός τε καὶ ταχέως διαδυόμενος διαψύχει. * * * Καταψύξεως μὲν οὖν ὅλως ἡ τῶν ζῴων δεῖται φύσις διὰ τὴν ἐν τῇ καρδίᾳ τῆς ψυχῆς ἐμπύρωσιν· ταύτην δὲ ποιεῖται διὰ τῆς ἀναπνοῆς, ὅσα μὴ μόνον ἔχουσι καρδίαν, ἀλλὰ καὶ πλεύμονα τῶν ζῴων. Τὰ δὲ καρδίαν μὲν ἔχοντα, πλεύμονα δὲ μὴ, καθάπερ οἱ ἰχθύες, διὰ τὸ ἔνυδρον αὐτῶν τὴν φύσιν εἶναι, τῷ ὕδατι ποιοῦνται τὴν κατάψυξιν διὰ τῶν βραγχίων.

Aristotle. Opera Omnia, Vol. iii., p. 547.

(17)

Ἡ δ' ἀναπνοὴ γίνεται αὐξανομενου τοῦ θερμοῦ, ἐν ᾧ ἡ ἀρχὴ ἡ θρεπτική· καθάπερ γὰρ καὶ τἆλλα δεῖται τροφῆς, κἀκεῖνο, καὶ τῶν ἄλλων μᾶλλον· καὶ γὰρ τοῖς ἄλλοις ἐκεῖνο τῆς τροφῆς αἴτιόν ἐστιν. Ἀνάγκη δὴ πλέον γινόμενον αἴρειν τὸ ὄργανον. Δεῖ δ' ὑπολαβεῖν τὴν σύστασιν τοῦ ὀργάνου παραπλησίαν μὲν εἶναι ταῖς φύσαις ταῖς ἐν τοῖς χαλκείοις· οὐ πόρρω γὰρ οὔθ' ὁ πλεύμων, οὔθ' ἡ καρδία πρὸς τὸ δέξασθαι σχῆμα τοιοῦτον· * * * ὅπερ φαίνονται ποιεῖν οἱ ἀναπνέοντες· αἴρουσι γὰρ τὸν θώρακα διὰ τὸ τὴν ἀρχὴν τὴν ἐνοῦσαν αὐτῷ τοῦ τοιούτου μορίου ταὐτὸ τοῦτο ποιεῖν· αἰρομένου γὰρ, καθάπερ εἰς τὰς φύσας, ἀναγκαῖον εἰσφέρειν τὸν ἀέρα τὸν θύραθεν, καὶ ψυχρὸν ὄντα καὶ καταψύχοντα σβεννύναι τὴν ὑπεροχὴν τὴν τοῦ πυρός. Ὥσπερ δ' αὐξανομένου ᾕρετο τοῦτο τὸ μόριον, καὶ φθίνοντος ἀναγκαῖον συνίζειν, καὶ συνίζοντος ἐξιέναι τὸν ἀέρα τὸν εἰσελθόντα πάλιν, εἰσιόντα μὲν ψυχρὸν, ἐξιόντα δὲ θερμὸν διὰ τὴν ἁφὴν τοῦ θερμοῦ τοῦ ἐνόντος ἐν τῷ μορίῳ τούτῳ, καὶ μάλιστα τοῖς τὸν πλεύμονα ἔναιμον ἔχουσιν· εἰς πολλοὺς γὰρ οἷον αὐλῶνας, τὰς σύριγγας ἐμπίπτειν τὰς ἐν τῷ πλεύμονι, ὧν παρ' ἑκάστην παρατέτανται φλέβες, ὥστε δοκεῖν ὅλον εἶναι τὸν πλεύμονα πλήρη αἵματος. Καλεῖται δ' ἡ μὲν εἴσοδος τοῦ ἀέρος ἀναπνοὴ, ἡ δ' ἔξοδος ἐκπνοή.

Aristotle. Opera Omnia, Vol. iii., p. 550.

(18)

Ἡ δὲ Πραξαγόρου τε καὶ Ἡροφίλου χρῆσις ἔτι καὶ εἰς τάδε κρατεῖ. Σφυγμὸν γὰρ οὗτοι πᾶσαν ἀρτηριῶν κίνησιν τὴν αἰσθητὴν καλοῦσιν. Οὕτως δὲ καὶ οἱ μετ' αὐτοὺς ἅπαντες, εἰ καὶ τοῖς ὁρισμοῖς διαφέρονται.

"The terms used by Praxagoras and Herophilus hold good to the present day. For every movement of the arteries they call a *pulse*, as is also the custom with all writers since their time, notwithstanding the variety of definitions employed."—*Galen. Opera Omnia*, Vol. viii., p. 498.

Ἀρτηρίας præterea vetustissimi Græci φλέβας, *venas*, vocaverunt. Quumque σφύζειν τὰς φλέβας, *venas micare*, dicebant, ἀρτηρίας intelligebant. Arteriarum enim micare, seu palpitare, munus est.

"The oldest Greek writers also called the arteries blood-vessels. And when they spoke of the blood-vessels pulsating, they meant the arteries. For to pulsate or palpitate is a function which belongs to the arteries."—*Rufus Ephesius. De Appellationibus*, Liber I., cap. xxxiv.

(19)

Τὸ μέν γε τοῦ Πραξαγόρου καὶ θαυμαστὸν ἴσως σοι φανεῖται. Μηδὲ γὰρ περιέχεσθαι λέγων ἐν ἀρτηρίαις τοὺς χυμοὺς, ὅμως ἐκ τῶν σφυγμῶν ἰδέας τινὰς αὐτῶν ἀναλογίζεσθαι πειρᾶται.

"You may, perhaps, be surprised at the view taken by Praxagoras. For though he denies altogether that there are in the arteries any liquid matters, he yet assumes to judge of their condition by means of the pulse."—*Galen. Opera Omnia*, Vol. viii., p. 941.

(20)

Θερμασίαν autem, *calorem*, atque *πνεῦμα*, *spiritum*, Zeno idem esse censuit; sed medici distinxerunt, *πνεῦμα*, quod spirando trahimus, *θερμασίαν* vero spiritus elisionem appellantes.

"According to Zeno, the vital heat and the pneuma are identical. But medical writers have made a distinction, understanding by *pneuma* what we take in by respiration, and calling the vital heat an emanation from it."—*Rufus Ephesius. De Appellationibus*, Liber i., cap. xxxvi.

(21)

Καὶ γὰρ οὖν καὶ τοὺς μῦς ὁ Ἐρασίστρατος ἐκ τοῦ πληροῦσθαι πνεύματος εἰς εὖρος ἐπιδιδόντας ἀφαιρεῖν φησι τοῦ μήκους, καὶ διὰ τοῦτ' ἀνεσπάσθαι.

"For Erasistratus says that the muscles also are drawn up from being filled with pneuma, increasing in breadth but diminishing in length."—*Galen. Opera Omnia*, Vol. viii., p. 429.

(22)

Herophilus venam crassissimam grandissimamque, ex corde pulmones petentem, ἀρτηριώδη, *arterialem* appellavit. In pulmonibus enim contra atque in aliis res habet. Nam venæ in his validæ sunt, proximéque ad arterialem naturam accedunt. Arteriæ, contra, imbecillæ, venarum que naturam sapiunt.—*Rufus Ephesius. De Appellationibus*, Lib. i., cap. xxxiii.

(23)

Πέρατα δ' ἐστὶ ταῦτα τῶν ἐπὶ τοῖς στόμασι τῆς καρδίας ὑμένων, ὑπὲρ ὧν Ἐρασίστρατος μὲν ἀκριβῶς ἔγραψεν.

"The extremities" (of the chordæ tendineæ) "are attached to the membranes at the orifices of the heart, which Erasistratus described minutely."—*Galen. Opera Omnia*, Vol. v., p. 206.

Αἰτία δὲ αἱ τῶν ὑμένων ἐπιφύσεις, ὑπὲρ ὧν αὐτάρκως Ἐρασιστράτου διειλεγμένου, περιττὸν ἡμᾶς νῦν γράφειν. Ἀλλ' ἐκεῖνος μὲν ἔοικεν ὑπολαμβάνειν, μηδὲν ὅλως εἰς τὴν καρδίαν ἐκ τῶν ἀρτηριῶν μεταλαμβάνεσθαι, πλήν γε διὰ τῶν ἐν πνεύμονι.

"This is owing to the attachment of the membranes" (valves), "which it is unnecessary to describe here, as they have been sufficiently treated of by Erasistratus. He, however, seems to have believed that nothing at all passes into the heart from the arteries in general, but only from those of the lung" (pulmonary veins).—*Galen. Opera Omnia*, Vol. v., p. 166.

Εἴρηται δὲ τὸ φαινόμενον ὑπὲρ Ἐρασιστράτου κατὰ τὴν τῶν πυρετῶν πραγματείαν, ὡς ὑμένες ἐπιπεφύκασι τοῖς στόμασι τῶν ἀγγείων, οἷς εἰς ὑπηρεσίαν ὑλῶν εἰσαγωγῆς τε καὶ αὖθις ἐξαγωγῆς ἡ καρδία προσχρῆται. Τούτους τοὺς ὑμένας ἐτόλμησάν τινες οὐκ εἶναι λέγειν, ἀλλ' ὑπ' Ἐρασιστράτου διεσκευάσθαι δόγματος ἕνεκεν κατασκευῆς. Πλὴν εἰς τοσοῦτον ἥκουσι γνώσεως ἅπασι τοῖς ἰατροῖς, ὥστ' ἀρχαῖος ὄντως εἶναι δόξειεν ἂν ὁ μὴ γινώσκων αὐτούς. Εἰσί δ' ἐπὶ μὲν τῷ στόματι τῆς κοίλης φλεβὸς τρεῖς ἀκίδων γλωχῖσιν ὁμοιότατοι τήν σύνταξιν, ὅθεν, οἶμαι, καὶ τριγλώχινας ἔνιοι τῶν Ἐρασιστρατείων ἐκάλεσαν αὐτούς· ἐπὶ δέ τῆς ἀρτηρίας τῆς φλεβώδους (οὕτω δὲ ὀνομάζω τὴν ἐκ τῆς ἀριστερᾶς κοιλίας τῆς καρδίας εἰς τὸν πνεύμονα κατασχιζομένην) ὁμοιότατοι μὲν τὸ εἶδος, ἀριθμῷ δ' οὐκ ἴσοι· μόνῳ γὰρ τούτῳ τῷ στόματι δυοῖν ὑμένων ἐπίφυσίς ἐστι, τῶν δ' ἄλλων στομάτων ἑκατέρῳ τρεῖς ὑμένες εἰσὶν ἅπαντες σιγμοειδεῖς. Ἐξάγει δ', ὡς Ἐρασίστρατός φησιν ἐξηγούμενος τὸ φαινόμενον, ἑκάτερον μὲν τῶν στομάτων αἷμα μὲν εἰς τὸν πνεύμονα ἕτερον αὐτῶν, πνεῦμα δ' εἰς ὅλον τὸ ζῶον ἕτερον. Τὸν τῶν ὑμένων, ὡς ἐκείνῳ δοκεῖ, πρός ἐναντίας ὑπηρεσίας τῇ καρδίᾳ χρόνον, ἀμοιβαῖς ἐγκαίροις ὑπαλλαττομένας, τοὺς μὲν ἐπὶ τοῖς εἰσάγουσιν τὰς ὕλας ἀγγείοις ἐπιπεφυκότας ἔξωθεν ἔσω φερομένους, ἀνατρέπεσθαι μὲν ὑπὸ τῆς εἰσόδου τῶν ὑλῶν, ἀναπίπτοντας δ' εἰς τὰς κοιλότητας τῆς καρδίας ἀνοιγνύντας τὰ στόματα παρέχειν ἀκώλυτον τὴν φορὰν τοῖς εἰς τὴν αὐτὴν ἑλκομένοις. Οὐ γὰρ δὴ αὐτομάτως γε τὰς ὕλας εἰσθεῖν φησιν, ὡς εἰς ἄψυχόν τινα δεξαμενὴν, ἀλλ' αὐτὴν τὴν καρδίαν διαστελλομένην, ὥσπερ τὰς τῶν χαλκέων φύσας, ἐπισπᾶσθαι πληροῦσαν τῇ διαστολῇ. Ἐπὶ δὲ τοῖς ἐξάγουσιν ἀγγείοις τὰς ὕλας ἐλέγομεν ἐπικεῖσθαι, καὶ *τοὐναντίον ἡγεῖσθαι πάθος πάσχειν, ἔσωθεν γὰρ ἔξω ῥέποντας, ἀνατρεπομένους μὲν ὑπὸ τῶν ἐξιόντων ἀνοιγνύναι τὰ στόματα, καθ' ὃν ἂν ἡ καρδία λόγον ἐχορήγει τὰς ὕλας· ἐν δὲ τῷ λοιπῷ παντὶ κλείειν ἀκριβῶς τὰ στόματα, μηδ' ἐνίας τῶν ἐκπεμφθέντων ἐπανέρχεσθαι συγχωροῦντας· οὕτως δὲ καὶ τοῖς ἐπὶ τοῖς εἰσάγουσι, ὅταν ἡ καρδία συστέλληται, κλείειν τὰ στόματα, μηδὲν τῶν ἑλχθέντων ὑπ' αὐτῆς αὖθις ἔξω παλινδρομεῖν ἐπιτρεπόντας.*

"Erasistratus, in his treatise on fevers, has described how membranes are attached to the mouths of the vessels which serve the heart in the alternate reception and expulsion of materials. Some have ventured to deny the existence of these membranes, implying that they were made up by Erasistratus for the purpose of supporting his doctrine; but they have now come to be so well known to physicians generally, that one would seem very ill informed not to be acquainted with them. At the mouth of the vena cava there are three, shaped very much like spear points; whence, I suppose, they were called 'tricuspids' (*τριγλώχινας*) by some of the Erasistrateans. Those at the arteria venalis, that is, the artery which has its ramification from the left ventricle of the heart into the lung, are of nearly the same form but not so many, for at this orifice the membranous appendages are two in number, while at each of the remaining mouths there are three, all of them sigmoid* in shape. Each of these (last) mouths, as Erasistratus

* The ancient Greek *sigma*, in the older monumental inscriptions, as well as in some existing manuscripts, has the form of **C**. The valves of the pulmonary artery and aorta were, therefore, properly named, from their semilunar or crescentic shape.

says, in his description, is a channel of exit, one of them for blood to the lung, the other for pneuma to the body at large. The use of the membranes, as he thinks, is to perform for the heart contrary functions, alternating at successive intervals. Those attached to the vessels which bring in materials, when pressed from without inward, yield to the influx of the materials, and, falling into the cavities of the heart, throw open its orifices and leave an unobstructed passage for what is drawn into it. For these matters, he says, do not come in of their own impulse, as into a passive receptacle; but the heart itself, expanding like a brazier's bellows, distends itself by its diastole. The membranes attached, on the other hand, to the vessels of exit, act in the contrary way. For, turning from within outward, they yield before the efflux, and open the orifices when the heart discharges its contents; while in the whole remaining interval they exactly close the orifices, preventing any return of what has been discharged."—*Galen. Opera Omnia*, Vol. v., p. 548.

The whole of the foregoing extract is given by Galen as representing the views of Erasistratus, and mainly for the purpose of contesting a part of its doctrine. Erasistratus claims that the cardiac valves, in their backward closure, entirely prevent regurgitation by complete occlusion of the orifices; while Galen believes that this occlusion is incomplete, allowing a partial reflux. His next sentence begins: "But if this be so, O Erasistrateans," etc., etc.

(24)

Although Galen lived at Rome, his works were written in Greek, as was customary at that time for books on scientific subjects. Modern writers employed Latin for the same purpose long after it was in disuse for any other. Two hundred years ago, it would have been thought very unprofessional for an important medical work to be published in English. Still later, Van Swieten's Commentaries (1742), Haller's Physiology (1757), Morgagni's Seats and Causes of Disease (1761), and Soemmering's Anatomy (1794), were printed in Latin; and even within the present century, such works as *Prochaska*, Disquisitio Anatomico-physiologica (1812); *Blumenbach*, Collectio Craniorum (1820); *Mascagni*, Anatomia Universa (1823); and *Otto*, Monstrorum Descriptio (1841), have appeared in the same classical dress.

(25)

The dogma of the ancients, that "nature abhors a vacuum," was only a truthful expression of the facts so far as they had been observed. It explained the non-occurrence of a vacuum by supposing a natural capacity in every movable body to extend itself into any adjacent space which would otherwise be empty; and by virtue of this tendency, the blood of the veins would penetrate into the neighboring arteries, whenever the latter were vacated by their escaping spirits. A similar property is now attributed to gases, which are capable of indefinite expansion; the ancients believed it to reside also in bodies of a liquid form.

(26)

Πειραθῆναι δὲ ἔστι παντὶ τῷ βουλομένῳ, καθότι καὶ ἡμεῖς ἐπειράθημεν πολλάκις τρώσαντες τὴν προειρημένην ἀρτηρίαν. Οὐ χαλεπῶς δὲ ἐξευρήσεις αὐτὴν καὶ πρὶν γυμνῶσαι τὸ δέρμα τῷ σφυγμῷ τεκμαιρόμενος. Διασημαίνει γὰρ ἡ κίνησις ἐν μὲν τοῖς ἰσχνοῖς ζώοις ἐπιπλέον, ἐν δὲ τοῖς πίοσιν πλησίον τοῦ κατ᾽ ὀλέκρανον ἄρθρου. Ταύτῃ τοίνυν, εἴπερ ἂν δεήσῃ, τιτρώσεις, ἢ γραφεῖον ὀρθώσας καὶ καθιεὶς, ἢ βελόνην, ἤ τι τῶν ἰατρικῶν μαχαιρίων τῶν ἰσχνῶν, ἤ τι τῶν παραπλησίων ὀργάνων, ὅσα βραχεῖαν δύναται ποιῆσαι τὴν διαίρεσιν, ἵνα τά τ᾽ ἄλλα πάνθ᾽, ὅσα πρόσθεν εἴρηται, κατὰ τὸν τόπον ἀποδείξῃς αὐτῶν, καὶ ὡς οὐδὲν οὔθ᾽ αἱ τῶν ἀρτηριῶν κινήσεις οὔθ᾽ αἱ τῶν μυῶν παραβλάπτονται.

Galen. Opera Omnia, Vol. iv., p. 715.

(27)

Γυμνοῦντες οὖν ἡμεῖς ἑκάστοτε μεγάλας ἀρτηρίας, ἃς ἐνδέχεται, μάλιστα δ᾽ ἐνδέχεται τὰς κατὰ κῶλα, τοὺς Ἐρασιστρατείους ἐρωτῶμεν, εἰ κἂν νῦν γοῦν, ὁπότε γεγύμνωνται, δοκοῦσιν ἐν αὐταῖς ἔχειν αἷμα. Οἱ δ᾽ ἐξ ἀνάγκης ὁμολογοῦσιν, ἅμα μὲν ὅτι καὶ αὐτὸς Ἐρασίστρατος αὐτὰς ἐν τῷ διαιρεῖσθαι τὸ δέρμα παρέμπτωσιν αἵματος ἐκ τῆς ἀρτηρίας γίγνεσθαί φησιν, ἅμα δ᾽ ὅτι καὶ τὸ φαινόμενον οὕτως ἔχει. Βρόχῳ γὰρ ἡμεῖς ἑκατέρωθεν τὰς γεγυμνωμένας ἀρτηρίας διαλαμβάνοντες, εἶτ᾽ ἐκτέμνοντες τοὐν μέσῳ, δείκνυμεν αἵματος μεστάς.

Galen. Opera Omnia, Vol. iv., p. 723.

(28)

"*The whole of the blood in the body is discharged from the wound.*" This statement is not strictly true, since a certain fraction of the blood, usually about one-fourth, remains in the vessels after death by hemorrhage, owing to failure of the heart's action. But it is valid in the sense intended by Galen, because enough blood is discharged to render the animal generally exsanguine, and to drain, not only the parts immediately adjacent to the wound, but also the vascular organs in the rest of the body.

(29)

This was a favorite dogma with some of the dialecticians at the school of Alexandria, who were fond of multiplying verbal discussions, to the frequent mystification of themselves and their hearers. The anatomists, on the other hand, held these metaphysical subtleties in something like contempt. One of the most noted of the dialecticians was Diodorus Cronos, whose argument against the existence of motion was as follows: "If anything moves, it must do so either in the place where it is, or in some other place. But it cannot move where it is, because as soon as it moves it is already somewhere else; and it cannot do so in any other place, because when it begins to move it has not yet arrived there." This acute philosopher one day suffered a dislocation of the shoulder, and came to Herophilus for treatment. But Herophilus objected. The shoulder, he said, could not have been dislocated without moving; and as it was impossible for it to move, of course it could not be dislocated.

Diodorus begged him to defer that question to another time, and to give him the benefit of his surgical skill; which Herophilus proceeded to do, and put the shoulder back into its place. This story is told by *Sextus Empiricus* (A. D. 200–250), Leipzig edition, 1840, Vol. i., p. 200.

(30)

The term χυλός, *chyle*, as used by Galen, did not mean the white, milky fluid found in the small intestines and lacteals, but the liquid juices extracted from the food by stomach digestion. The original signification of the word is simply a "juice," generally that expressed from fruits or vegetables; and it was also applied by anatomists to the nutritious liquids of animal tissues. After the discovery of the lacteals and lymphatics in the seventeenth century, its use was restricted to the milky emulsion produced by the digestion of oleaginous matters.

(31)

Ἡ τοὺς σφυγμοὺς ἐργαζομένη δύναμις.
Galen. Opera Omnia, Vol. ix., p. 6.

(32)

Ἐπεὶ τοίνυν ἡ καρδία τῆς ἐμφύτου θερμασίας, ᾗ διοικεῖται τὸ ζῶον, οἷον ἑστία τέ τίς ἐστι καὶ πηγὴ, κ. τ. λ. *Galen. Opera Omnia*, Vol. iii., p. 436.

(33)

The word used in this sense is ψύχω, to cool by breathing or blowing upon, with its compounds ἀναψύχω, καταψύχω, and ἐμψύχω.

(34)

The ancient cupping vessels were made of bronze, and were long and narrow, like a cucumber; whence their name, *σικύαι*.

(35)

Ἐξ *ἁπάντων οὖν τούτων ἔστιν ἀποδέξασθαι τῶν λεγόντων, τῆς ἐμφύτου θερμασίας ἕνεκεν ἀναπνεῖν τὰ ζῶα.* Καὶ *γὰρ τὸ ῥιπίζεσθαι συμμέτρως χρήσιμον, καὶ τὸ μετρίως ψύχεσθαι.* Ἄμφω *γὰρ ταῦτα φαίνεται ῥωννύντα τὴν εἴσω θερμασίαν, κίνησίν τε ἀναγκαῖον ἔχειν κάτω τὸ καπνῶδες, ὡς ἂν εἴποι τις, ἐκκενοῦν τῆς τοῦ αἵματος συγκαύσεως.*

Galen. Opera Omnia, Vol. iv., p. 492.

(36)

Ἐ*κδέχεται δ' αὐτῶν ἐνταῦθα μία φλὲψ μεγίστη, ἐκ τῶν κυρτῶν τοῦ ἥπατος διαπεφυκυῖα, πρὸς ἄμφω τοῦ ζώου τὰ μέρη φερομένη, τό τε ἄνω καὶ τὸ κάτω.* Φ*αίης ἂν οἷον ἀγωγόν τινα μεστὸν αἵματος ὑπάρχουσαν αὐτὴν, καὶ ὀχετοὺς παμπόλλους ἀποῤῥέοντας ἴσχειν, ἐλάττους τε καὶ μείζους, εἰς πᾶν μόριον τοῦ ζώου νενεμημένους.*

Galen. Opera Omnia, Vol. iii., p. 272.

(37)

Σ*αφέστατα δ' ἂν αὐτὸ μάθοις ἐπὶ τῶν ἐν τοῖς κήποις ὀχετῶν.* Ἐ*κ τούτων γὰρ εἰς μὲν τὰ παρακείμενα καὶ πλησίον ἅπαντα διαδίδοταί τις ἰκμὰς, εἰς δὲ τὰ ποῤῥωτέρω προσελθεῖν οὐκέτι δύναται· καὶ διὰ τοῦτο ἀναγκάζονται πολλοῖς ὀχετοῖς μικροῖς ἀπὸ τοῦ μεγάλου τετμημένοις εἰς ἕκαστον μέρος τοῦ* κήπου τὴν ἐπίῤῥυσιν τοῦ ὕδατος ἐπιτεχνᾶσθαι· καὶ τηλικαῦτά γε τὰ μεταξὺ διαστήματα τούτων τῶν μικρῶν ὀχετῶν ποιοῦσιν, ἡλίκα μάλιστα νομίζουσιν ἀρκεῖν εἰς τὸ ἱκανῶς ἀπολαύειν ἕλκοντα τῆς ἑκατέρωθεν αὐτοῖς ἐπιῤῥεούσης ὑγρότητος. Οὕτως οὖν ἔχει κἀν τοῖς τῶν ζώων σώμασιν. Ὀχετοὶ πολλοὶ κατὰ πάντα τὰ μέρη διεσπαρμένοι παράγουσιν αὐτοῖς αἷμα, καθάπερ ἐν κηπίῳ ὑδρείαν τινά. Καὶ τούτων τῶν ὀχετῶν τὰ μεταξὺ διαστήματα θαυμαστῶς ὑπὸ τῆς φύσεως εὐθὺς ἐξ ἀρχῆς διατέτακται πρὸς τὸ μήτ' ἐνδεῶς χορηγεῖσθαι τοῖς μεταξὺ μορίοις ἕλκουσιν εἰς ἑαυτὰ τὸ αἷμα, μήτε κατακλύζεσθαι ποτ' αὐτὰ πλήθει περιττῆς ὑγρότητος ἀκαίρως ἐπιῤῥεούσης.

Galen. Opera Omnia, Vol. ii., p. 210.

(38)

Ἡμεῖς δὲ καὶ δι' ἑτέρου τινὸς ὅλου βιβλίου πολυειδῶς ἀπεδείξαμεν, αἷμα κἀν τῷ κατὰ φύσιν ἔχειν τὸ ζῶον ἐν αὐταῖς ταῖς ἀρτηρίαις περιέχεσθαι. Εἰ δὲ τοῦτο, παντί που δῆλον, ὡς οὐχ, ὅτι πληροῦνται τοῦ παρὰ τῆς καρδίας ἐπιπεμπομένου πνεύματος, ὡς Ἐρασίστρατος ἐνόμιζε, διὰ τοῦτο διαστέλλονται μᾶλλον, ἤ, ὅτι διαστέλλονται, διὰ τοῦτο πληροῦνται. Κενῶν μὲν γὰρ αἵματος οὐσῶν, ἐνδέχοιτ' ἂν ἴσως ἐν ὀλίγῳ χρόνῳ τὸ ἀπὸ τῆς καρδίας ἐπιῤῥυὲν ἐξικέσθαι μέχρι τῶν περάτων· αἷμα δὲ εἴπερ ἔχοιεν, οὐδαμῶς ἐγχωρεῖ τὸ τάχος τῆς κινήσεως ὁμολογεῖν τῷ παρὰ τῆς καρδίας πληρουμένας αὐτὰς διαστέλλεσθαι. Οὐ γάρ, ὅτι πληροῦνται, διὰ τοῦτο διαστέλλονται, ἀλλ' ὅτι διαστέλλονται, διὰ τοῦτο πληροῦνται.

Galen. Opera Omnia, Vol. v., p. 168.

(39)

Συναναστόμωνται μὲν αἱ ἀρτηρίαι ταῖς φλεψὶ καθ' ὅλον τὸ σῶμα, καὶ μεταλαμβάνουσιν ἐξ ἀλλήλων αἷμα καὶ πνεῦμα διά τινων ἀοράτων τε καὶ στενῶν ἀκριβῶς ὁδῶν.

Galen. Opera Omnia, Vol. iii., p. 455.

(40)

It is noticeable how this doctrine corresponds with what is known at present, as to the relative composition of arterial and venous blood; arterial blood containing a large quantity of oxygen and but little carbonic acid, while in venous blood there is a scanty proportion of oxygen and abundance of carbonic acid.

(41)

These infundibuliform depressions on the surface of the septum, in the right ventricle, are interspaces between the muscular bundles, which are more or less prominent and interlace with each other. In the human heart they are plainly enough visible, but very shallow. In the heart of the ox they are deeper, often admitting a probe to the depth of one-quarter to three-quarters of an inch. In the dog's heart they are few in number, from one-eighth to three-eighths of an inch deep, and usually in the form of elongated clefts. In the sheep and pig they are hardly noticeable, except along the borders of the conus arteriosus. It must be acknowledged that where they are well developed, as in the heart of the ox, they are frequently seen also on the inner surface of the *outer* wall of the ventricle, where, according to Galen, they would be of no use.

(42)

Galen's estimate of the comparative size of the cardiac orifices, as they appear to the eye, is correct. All anatomists are agreed that the auriculo-ventricular orifice on the right side is considerably larger than that of the pulmonary artery; the tricuspid valves, which are thin and flaccid, like the sigmoid, lying back in contact with the walls of the ventricle. The mitral valves, in the left ventricle, are thicker and stiffer. The large one, on the inner side, slants downward and outward, reducing the auriculo-ventricular orifice, when viewed from above, to a somewhat narrow and irregular opening of triangular form; while the aortic orifice, just below the sinuses of Valsalva, when viewed from the same direction, is nearly circular in form and looks decidedly larger. This is especially noticeable in the heart of the ox, where the valves and their fibrous attachments are quite thick, and the cadaveric rigidity of the muscular walls nearly always strongly pronounced. Herbert Davies (*Proceedings of the Royal Society of London*, March 17th, 1870) makes the area of the mitral opening larger than that of the aortic; the difference between them, according to him, being the same as that between the tricuspid and pulmonary. But in his estimate the area of each opening was calculated from its circumference, assuming in every case the form of the orifice to be that of a circle; and this assumption is vigorously disputed by other writers.

(43)

The razor of the fourteenth century may have had a form better adapted for anatomical purposes than our own; but, in any case, the use of such an instrument, and the want of any other especially intended for dissection, show the low grade of the medical sciences at that time.

(44)

Additamenta cordis sunt quedam partes pelliculares, apte ad dilatandum et constringendum, genite ad hoc ut quum in corpore nostro generatur multum de sanguine, vel de spiritu in ventriculo sinistro, dilatentur ut contineant sanguinem multum, vel spiritum multum, qui interdum generatur. * * * Secunda causa fuit quia cúm non semper generetur in nobis multa quantitas spiritus, et etiam sanguinis, cúm cor fuisset magnum, ut plurimum concavitas cordis extitisset vacua, sed quia iste auricule possunt faciliter contrahi quum non sunt replete, ibi non erit vacuitas.—*Mundinus.* Chapter *De Anathomia cordis.*

(45)

Primo quia hic ventriculus debet continere spiritum, dexter vero sanguinem, sanguis autem gravior est spiritu, propter quod ratione contentorum plus aggravaret pars dextra quam sinistra, et ideo cor non fuisset equalis stature: ut illa esset equalis ponderis fecit (natura) parietem sinistram grossiorem, ut recompensaret sua gravitate gravitati sanguinis.—*Mundinus.* Chapter entitled *Paries cordis intrinsece.*

(46)

Mondini's book contains a number of anatomical terms, some of them, no doubt, derived from the

Arabic, which are strange to modern ears. For example: the vena cava is the *vena chilis;* the caput coli is the *monoculum;* the front wall of the abdomen is *myrach;* the peritoneum is *cyphach;* the œsophagus is *meri* (indeclinable); the omentum is *zyrbus;* and the mesentery is *eucharum.*

(47)

Figuram habet pyramidalem, gibbam tamen, non talem principaliter quia sit calidum, ignis sequens formam, sed quia est mixtum, perfectum, animatum, possidet formam operi suo competentem.—*Carpus. Isagogæ*, Chapter *De Corde.*

(48)

Jacobus Sylvius (Jacques Dubois) was a teacher of anatomy at Paris from about the year 1530 to 1555; the latter part of the time as professor in the Royal College of France. He was distinguished for the attractive style of his lectures and demonstrations, and for his observations on the structure of the brain. It is from him that the *fissure of Sylvius* and the *aqueduct of Sylvius* derive their names.

(49)

These details concerning the life of Vesalius are drawn mainly from the preface, by Boerhaave and Albinus, in their edition of his complete works, published at Leyden in 1725.

(50)

We do not find that Galen anywhere asserts that he dissected the human body, at least habitually. He often refers to his experiments and observations on various animals. In his opening chapter on the "Anatomy of the Veins and Arteries," he expressly states that this book is a compendium of the dissection which his pupil has seen performed "on the body of the ape;" and his prolongation of the cavities of the cerebral ventricles into the olfactory lobes (*Opera Omnia*, Vol. ii, p. 859) evidently represents this formation in the brain of the rodentia, carnivora, ruminantia, and pachydermata.

(51)

It is not always easy to understand the importance attached to certain points by the writers of former times. Vesalius, for example, devotes the sixth chapter of his third book mainly to a discussion with Galen whether the vena cava takes its origin from the liver or from the heart. As there is no difference between them in regard to the physiology of the parts, or the course of the blood at either point, the question as to whether the vein may be said to "originate" from one organ or the other seems like a dispute about words. But it had, no doubt, in the mind of the author, some significance which we fail to perceive.

(52)

Vtriusq; uẽtriculi superficies perquàm inaequalis est, & multis quasi foueis in carneã substantiam penitius impressis obsita. Neq; istae ad latera tãtum cõsistunt, quibus dexter uẽtriculus sinistrũ respicit, uerùm (etsi interim secus caeteris omnib. Anatomen profitentibus uisum sit) per uniuersam prorsus uentriculorũ superficiem, nõ solùm in nuper occisis animantibus, sed perpetuò, tãtisper dum cor ipsum seruare uolueris, apparentes, neq; unquã uel in exiccato corde cõniuentes. Vtcũq; interim hae foueae sint cõspicuae, nullae tamen, quod sensu cõprehendi potest, ex dextro uentriculo in sinistrũ per eorundẽ uentriculorũ septũ permeãt: neq; etiã mihi meatus uel obscurissimi occurrũt, quibus uentriculorũ septum sit peruiũ, quãuis illi à dissectionum professorib. enarrẽtur, quũ sanguinẽ ex dextro uẽtriculo in sinistrum assumi persuasissimũ habẽt. Vnde etiã fit (quemadmodũ quoq; alicubi monebo apertius) de cordis hac in parte officio, me haud mediocriter ambigere.—*Vesalius. De Humani corporis fabrica*, Liber VI., cap. xi.

(53)

In cordis itaq; cõstructionis ratione, ipsiusq́; partium usu recensendis, magna ex parte Galeni dogmatibus sermonem accommodaui: non sanè, quòd undiq; haec ueritati consona existimem, uerùm quòd in nouo passim partium usu officioq́; referendo, adhuc mihi diffidam, neq; ita pridem de medicorum principis Galeni sentẽtia uel latum unguem hîc declinare ausus fuerim. Haud enim leuiter studiosis expendendũ est uentriculorum cordis interstitium, aut septum, ipsumúe sinistri uentriculi dextrum latus, quod aequè crassum cõpactumq́; ac densum est atq; reliqua cordis pars, sinistrum uentriculũ complectẽs. Adeò ut ignorem (quicquid etiam de foueis hac in sede cõmenter, & uenae portae ex uentriculo & intestinis suctionis non sim immemor) quî per septi illius substantiam ex dextro uentriculo in sinistrum uel minimũ quid sanguinis assumi possit.—*Vesalius. De Humani corporis fabrica*, Liber VI., cap. xv.

(54)

Huius uenae rami, per iecoris corpus exporrecti, portae ramis incumbunt, & utriusq; uenae ramulorum extrema osculis inter se conniuent, & multis locis congredi continuariq́; iam dissecantibus apparent.—*Ibid.*, Liber III., cap. vi.

(55)

Atque quum haec animo obuersantur, simul sese multa in arteriarum serie offerunt, de quibus non immeritò uenit ambigendum: nimirum nullam ferè uenam absq; comite arteria uentriculum ac intestina, lîenemq́; adeò ipsum petere, & ferè totam portae uenam sua serie comitem sibi arteriam asciscere. Denique renibus arteriae tam grandes communicantur, ut neutiquam ad illorum calorem duntaxat temperandum eas productas esse queamus affirmare: uti minus adhuc solius caloris nativi gratia tantas arterias uentriculo, intestinis, lieniq́; insertas esse, possimus asserere. His accedit, quòd per uenas arteriasq́; mutuos materierũ fluxus & refluxus esse, ac nihil prorsus grauitatem & pondus materierũ in uenis arterijsq́; agere, plurimis argumentis oporteat fateri.—*Ibid.*, Liber VI., cap. xv.

The foregoing extracts are from the revised edition of Vesalius' work, printed in 1555. In his first issue he does not impugn the porosity of the cardiac septum, or the transudation of blood through it according to Galen. He published his doubts on this subject only after mature consideration, and after finding them confirmed by repeated observation.

(56)

Vesalius was appointed physician to the emperor, Charles V., in 1544. This appointment was a perfectly natural one. The emperor, by birth Duke of Burgundy and sovereign of the Low Countries, inherited the crown of Spain from his maternal grandfather; but he was born and educated in the Netherlands, and was always more of a Fleming than a Spaniard. He was proud of the success and reputation of Vesalius; and when he established his court at Madrid he gave the anatomist the highest professional appointment at his command.

(57)

The personal history of Servetus, so far as known, is to be found in *De la Roche*, Memoirs of Literature, London, 1722, Vol. iv., pp. 73, 127, 187, 264, 299, 319; *Mosheim*, Ecclesiastical History, Ancient and Modern, English edition, Berwick, 1819, Vol. iv., p. 488; *Biographie Universelle*, Paris, 1825, article Servet; and *Willis*, Servetus and Calvin, London, 1877.

(58)

Even Mosheim, who was chancellor of the University of Göttingen, and reputed to be very learned in such matters, says, in his *Ecclesiastical History*, that "it is difficult to unfold, in a few words, the doctrine of this unhappy man; nor indeed would any detail render it intelligible in all its branches." And De la Roche, in his *Memoirs of Literature*, says that Servetus sometimes "expresses himself so confusedly that 'tis no easy thing to have a notion of his doctrine."

(59)

Ad quam rem est prius intelligenda substantialis generatio ipsius vitalis spiritus, qui ex aëre inspirato et subtilissimo sanguine componitur et nutritur. Vitalis spiritus in sinistro cordis ventriculo suam originem habet, iuuantibus maxime pulmonibus ad ipsius generationem. Est spiritus tenuis, caloris vi elaboratus, flauo colore, ignea potentia, vt sit quasi ex puriori sanguine lucidus vapor, substantiam in se continens aquæ, aëris et ignis. Generatur ex facta in pulmonibus mixtione inspirati aëris cum elaborato subtili sanguine, quem dexter ventriculus cordis sinistro communicat. Fit autem communicatio hæc, non per parietem cordis medium, ut vulgo creditur, sed magno artificio a dextro cordis ventriculo, longo per pulmones ductu, agitatur sanguis subtilis: a pulmonibus præparatur, flauus efficitur: et a vena arteriosa in arteriam venosam transfunditur. Deinde in ipsa arteria venosa inspirato aëri miscetur, expiratione a fuligine repurgatur. Atque ita tandem a sinistro cordis ventriculo totum mixtum per diastolem attrahitur, apta supellex, vt fiat spiritus vitalis.

Quod ita per pulmones fiat communicatio, et præparatio, docet coniunctio varia, et communicatio venæ arteriosæ cum arteria venosa in pulmonibus. Confirmat hoc magnitudo insignis venæ arteriosæ, quæ nec talis, nec tanta facta esset, nec tantam a corde ipso vim purissimi sanguinis in pulmones emitteret, ob solum eorum nutrimentum, nec cor pulmonibus hac ratione seruiret; cum præsertim antea in embryone solerent pulmones ipsi aliunde nutriri, ob membranulas illas, seu valuulas cordis, vsque ad horam natiuitatis nondum opertas, vt docet Galenus. Ergo ad alium vsum effunditur sanguis a corde in pulmones hora ipsa natiuitatis, et tam copiosus. Item a pulmonibus ad cor non simplex aër, sed mixtus sanguine mittitur, per arteriam venosam: ergo in pulmonibus fit mixtio. Flauus ille color a pulmonibus datur sanguini spirituoso, non a corde. In sinistro cordis ventriculo non est locus capax tantæ et tam copiosæ mixtionis, nec ad flauum elaboratio illa sufficiens. Demum, paries ille medius, cum sit vasorum et facultatum expers, non est aptus ad communicationem et elaborationem illam, licet aliquid resudare possit. Eodem artificio, quo in hepate fit transfusio a vena porta ad venam cauam propter sanguinem, fit etiam in pulmone transfusio a vena arteriosa ad arteriam venosam propter spiritum. Si quis hæc conferat cum iis quæ scribit Galenus lib. 6 et 7 de vsu partium, veritatem penitus intelliget, ab ipso Galeno non animaduersam.—*Servetus. Christianismi Restitutio*, p. 170.

(60)

Secunda alia ratione facti sunt ventriculi illi, vt ad spatia eorum inania penetrans per ossa ethmoide inspirati aëris portio, et ab ipsis animæ vasis per diastolem attracta, animalem intus contentum spiritum reficiat et animam ventilet. In vasis illis est mens, anima et igneus spiritus, iugi flabellatione indigens: alioquin, instar externi ignis, conclusus suffocaretur. Flabellatione et difflatione instar ignis indiget, non solum, vt ab aëre pabulum sumat, sed vt in eum suam fuliginem evomat. Sicut elementaris hic externus ignis terreo crasso corpori, ob communem siccitatem, et ob communem lucis formam, alligatur, corporis liquorem pabulum habens, et ab aëre difflatur, fovetur, et nutritur; ita igneus ille noster spiritus et anima corpori similiter alligatur, unum cum eo faciens, eius sanguinem pabulum habens; et ab aëreo spiritu, inspiratione et expiratione, difflatur, fovetur et nutritur, vt sit ei duplex alimentum, spirituale et corporale. Hac loci et spiritualis fomenti ratione conveniens admodum fuit, eundem nostri spiritus lucidum natura locum spiritu alio sancto, cælesti, lucido, afflari, idque per oris Christi expirationem, sicut a nobis inspiratione in eundem locum trahitur spiritus. Decuit eundem nostri intellectus, et lucentis animae locum, cælesti alterius ignis luce denuo illuminari. Nam Deus primam in nobis lucernam illuminat, et subortas ibi tenebras denuo vertit in lucem, vt ait Dauid, psalm. 17 et 2 Sam. 22. Idipsum docet Elihu apud Iob, cap. 32 et 33. Idipsum docuerunt Zoroaster, Trismegistus et Pythagoras, vt mox citabo. Vasorum quoque formatio et temperies bona ad mentis bonitatem facit, vt illis sit anima melior, quibus sunt illa melius disposita. Sicut vero a bono spiritu insita illa lux magis et magis illuminatur, ita et a malo obscuratur. Si in vascula illa cerebri, cum animali nostro lucido spiritu tenebrosus et nequam spiritus intrudatur, tunc dæmoniacos furores videbis, sicut per bonum spiritum lucidas reuelationes. Vascula autem illa facile impetit spiritus nequam, qui sedem habet vicinam in abyssis illis aquarum, et lacunis ventriculorum cerebri. Spiritus ille nequam, cuius potestas est aëris, una cum inspirato a nobis aëre, lacunas illas libere ingreditur et egreditur, vt ibi cum spiritu nostro, intra vasa illa velut in arce collocato, iugiter dimicet. Imo eum ita undique obsidet, vt vix illi liceat respirare, nisi quum superveniens lux spiritus Dei malum spiritum fugat. Ecce quam decenter loco illi conveniat, mentis, spiritus, reuelationis, et intellectus ratio, et insita et superveniens, et tentationum superiorum pugna, ut alias nunc tentationes omittam.—*Servetus. Christianismi Restitutio*, p. 173.

(61)

According to Mosheim, "even his plans of reformation fell into oblivion after the death of their author."—*Ecclesiastical History*, Vol. iv., p. 492.

(62)

Inter hos ventriculos septum adest, per quod fere omnes existimant sanguini à dextro ventriculo ad sinistrum aditum patefieri. id vt fiat facilius, in transitu ob vitalium spirituum generationem tenuem reddi. sed longa errant via; nam sanguis per arteriosam venam ad pulmonem fertur, ibiq; attenuatur; deinde cum aere vnà per arteriam venalem ad sinistrum cordis ventriculum defertur.—*Colombo. De Re Anatomica*, p. 177.

(63)

Hæc vero tria vasa à substantia rara, porosa, leuiq́; amplectuntur, itaq; pulmo gignitur: cuius vsus est, vt recte Anatomici scribunt, ob cordis refrigerationem;

quod efficit, aerem ad illud frigidum deferens. factus præterea fuit pulmo ad inspirationem, atq; expirationem, & vt voci deseruiat. Atq; hos omnes pulmonis vsus nouerunt, qui ante me scripsere. præter quos ego aliùm addo maximi momenti, de quo ne per transennam quidem meminere. Est autem præparatio, & pene generatio vitalium spirituum, qui postmodum in corde magis perficiuntur. Aerem namq; per nares, & os inspiratum suscipit; nam asperae arteriae vehiculo per vniuersum pulmonem fertur, pulmo vero aerem illum vnà cum eo sanguine miscet, qui à dextro cordis ventriculo profectus per arterialem venam deducitur. Vena enim hæc arterialis præterquam quòd sanguinem pro sui alimento defert; adeo ampla est, vt alíus vsus gratia deferre possit. Sanguis huiusmodi ob assidui pulmonum motum agitatur, tenuis redditur, & vnà cum aere miscetur, qui et ipse in hac collisione, refractioneq; præparatur; vt simul mixti sanguis, & aer per arteriæ venalis ramos suscipiantur: tandemq́; per ipsius truncum ad sinistrum cordis ventriculum deferantur; deferuntur vero, tam belle mixti, atq; attenuati, vt cordi exiguus præterea labor supersit: post quam exiguam elaborationem, quasi extrema imposita manu vitalibus hisce spiritibus, reliquum est, vt illos ope arteriæ ahorti per omnes corporis partes distribuat.—*Colombo. De Re Anatomica*, p. 223.

(64)

Non vereor quin nouus hic pulmonum vsus, quem nemo Anatomicorum hactenus somniauit, incredulis, atque Aristotelicis paradoxon videri debeat, quos oro, rogoq́; vt pulmonis magnitudinem contemplentur, quæ absq; vitali sanguine permanere non poterat;

cum nulla sit tam minima corporis particula, quæ illo destituatur. Quod si vitalis hic sanguis in pulmonibus non gignitur: à qua parte transmitti poterat, præterquam ab ahorti arteria? at ab ahorti arteria ramus nullus, neq; magnus, neque paruulus ad pulmones mittitur. Nam quo pacto per venam, aut per arteriam venalem deferri sanguis vitalis ad pulmonem potest, cum neutra pulset? hæc igitur candide lector, quam dixi, arterialis vena* constructa fuit, vt sanguinem eo, quo diximus, pacto elaboratum intro afferret ad cor ipsum: non vt à corde eliciat & extra ferat.—*Colombo. De Re Anatomica*, p. 223.

(65)

Ad hæc, quæ diximus, illa etiam accedit ratio, Medicos tunc è pulmonibus manantem sanguinem coniectare, atque adeo certo scire, longo rerum vsu edoctos, non modo quòd cum tussi eliciatur, sed etiam quia floridus est, tenuis, & pulcher, vt de sanguine arteriarum quoque dicere consueuerunt.—*Colombo. De Re Anatomica*, p. 224.

(66)

Tu vero candide lector doctorum hominum studiose, veritatis autem studiosissime, experire, obsecro, in brutis animantibus, quæ viua vt seces, moneo, atque hortor; experire inquam, an id, quod dixi, cum re ipsa consentiat: nam in illis arteriam venalem illius modi sanguinis plenam inuenies, non aere plenam, aut fumis, vt vocant, si Deo placet, capinosis, illi duntaxat pulsus deest.—*Colombo. De Re Anatomica*, p. 224.

* This is evidently a misprint for *arteria venalis*.

(67)

Dicitur ob officium ARTERIA. Nam I. pulsat, siquidem sinistro ventriculo continua est. II. Aërem continet & devehit.—*Casp. Bartholini Institutiones Anatomicæ, ab auctoris filio Thoma Bartholino.* Lugd. Batavorum, 1641. Lib. II., cap. vii., p. 214.

(68)

Idcirco pulmo per venam arterijs similem ex dextro cordis ventriculo feruidum hauriens sanguinem, eumque per anastomosim arteriæ venali reddens, quae in sinistrum cordis ventriculum tendit, transmisso interim aere frigido per asperæ arteriæ canales, qui iuxta arteriam venalem protenduntur, non tamen osculis communicantes, vt putauit Galenus, solo tactu temperat.—*Caesalpinus. Quæstionum Peripateticarum*, Lib. V., quæst. iiii., p. 125 D.

(69)

Pulchrè igitur condita sunt omnia: Cum enim feruere oporteret in corde sanguinem, vt fieret alimenti perfectio: primò quidem in dextro ventriculo, in quo crassior adhuc continetur sanguis, deinde autem in sinistro vbi syncerior iam sanguis est: partim per medium septum, partim per medios pulmones refrigerationis gratia ex dextro in sinistrum transmittitur.—*Caesalpinus. Quæstionum Peripateticarum*, Lib. V., quæst. iiii., p. 126 A.

(70)

The claims of Caesalpinus to a knowledge of the general circulation are given at especial length by

De Renzi, in his *Storia della Medicina in Italia.* Napoli, 1844–48. Tom. III., cap. iv., art. 8. The author, who is fully imbued with patriotic fervor, combats zealously the opinion of adverse critics; and he makes the naïve remark (p. 379), that "if those who would detract from the glory of Italy and Caesalpinus are foreigners" he will excuse them, because they "*have no inward motive for seeking the truth;*" while if they are Italians, he considers them as suicidal monomaniacs.

(71)

Qua autem ratione fiat alimenti attractio, & nutritio in plantis, consideremus. Nam in animalibus videmus alimentum per venas duci ad cor tanquam ad officinam caloris insiti, & adepta inibi vltima perfectione per arterias in vniuersum corpus distribui agente spiritu, qui ex eodem alimento in corde gignitur.—*Caesalpinus. De Plantis,* Lib. I., cap. ii., p. 3.

(72)

Quod si cor principium est sanguinis, venarum quoque & arteriarum principium esse necesse est: vasa enim hæc sanguini sunt destinata. Vt igitur riuuli ex fonte aquam hauriunt, sic venæ & arteriæ ex corde.—*Caesalpinus. Quæstiones Peripateticæ,* Lib. V., quæst. iii., p. 116 A.

(73)

Vtræque autem ex eodem principio fluunt scilicet corde, quia principium vnum esse melius est quam plura, & propter alias causas superius dictas: ex dextro quidem eius ventriculo amplissimo & calidissimo vena caua, sanguinem enim continet crassiorem, in quo calor intensus est magis. Ex altero autem ventriculo qui medius est, ac minor, sanguinem temperatissimum ac syncerissimum habente egreditur Aorta ex latere sinistro.—*Caesalpinus. Quæstiones Peripateticæ*, Lib. V., quæst. iii., p. 118 A.

(74)

Ex corde egrediuntur venæ & arteriæ, quarum illæ quæ ad caput feruntur caluariam ingressæ partim in ventriculis cerebri plexus retis modo efficiunt: partim verò in membrana duriore sinus quosdam communes ex vtraque vena constituunt, è quibus vasa sanguinis in tenuem membranam sparguntur.—*Caesalpinus. Quæstiones Peripateticæ*, Lib. V., quæst. iii., p. 120, F.

(75)

Vena caua materiam subministrat ex hepate, quod alimentum auctivum vocat Aristoteles. Aorta perfectum recipit, quod alimentum nutritivum, quia dat esse. —*Caesalpinus. Speculum Artis Medicæ*, Lib. VI., cap. ix., p. 443.

(76)

Venæ latæ duæ, a quibus multi rami sparguntur, Porta & caua, quarum veluti radicatio in hepate est. Ex Porta rami multi ad intestina & ventriculum tendunt, una cum arteriis per mesenterium, unde venæ mesaraicæ vocantur, sugentes chylum, vt ferant ad hepar, et interim in sanguinem conuertunt. * * *

Vena autem caua ramos in totum corpus dispergit, vt simul cum arteriis vniuersas partes nutriant.—*Caesalpinus. Speculum Artis Medicæ*, Lib. VII., cap. i., p. 488.

(77)

Sanguis ergo venarum fibris et crassitie sua *nutrit;* at arteriarum spiritibus et calore *vivificat.*—*Spigelius. De Humani Corporis fabrica*, Lib. V., cap. i.

Est autem vena, si definitionem ipsius requires, vas membranosum, sanguinem fibrosum et crassiorem, *pro nutritione* totius corporis omnium que partium, conficiens et deferens.—*Ibid.*, Lib. V., cap. i.

Et fit (sanguis) spirituosus, sicque per arteriam magnam in universum corpus *pro vita* singularium partium pellitur.—*Ibid.*, Lib. VI., cap. vi.

Venæ alimentum suppeditant; arteriæ flammæ spiritum recipiunt.—*Caesalpinus. Quæstiones Peripateticæ*, quæst. iiii.

Arteria magna, per quam cor universo corpori *vitam* communicat.—*Falloppius. Institutiones Anathomicæ*, cap. *De Thoracis.*

(78)

Primo enim venarum sanguis fibrosior est, id est, plures habet fibros. Secundo idem quoque crassior est, dum contrà arteriarum sanguis attenuatus sit magis per coctionem, eam scilicet quæ in corde fit. Color quoque utriusque sanguinis discrimen evestigio exprimit; cum ille, nigrior sit; hic rubicundus: ille, spirituum expers; hic prægnans: ille, quiete fruens; hic perpetuo et indesinente motu agitatus.—*Spigelius. De Humani Corporis fabrica*, Lib. V., cap. i.

(79)

Motus continuus a corde in omnes corporis partes agitur, quia continua est spiritus generatio qui sua amplificatione diffundi celerrime in omnes partes aptus est, simul autem alimentum nutritivum fert, *et auctivum ex venis elicit per osculorum communionem quam Graeci anastomosim vocant.—Caesalpinus. Quæstiones Peripateticæ*, Lib. V., quæst. iv., p. 123 B.

Nam præterquam quod omnes arteriæ sanguinem & alias humores, nisi admodum ii crassi fuerint, *a singulis venis per communes anastomoses recipiunt.—Eustachius. Opuscula Anatomica. De Renum Officio*, cap. xxix.

Internæ vero (arteriæ) & spiritum & vaporem & sanguinem trahunt: spiritum a corde, vt sit caloris influentis vehiculum; vaporem, vt sit pabulum vitalis spiritus, & *sanguinem à vicinis venis per occultas anastomoses*, ad sui nutritionem.—*Laurentius. Historia Anatomica humani corporis*, Lib. IV., cap. ix.

(80)

Illæ quoque arteriæ, quæ in mesenterio distributæ sunt, chylum ipsum, *non secus ac mesenterii ipsius venæ*, attrahunt et conficiunt.—*Eustachius. Opuscula Anatomica. De Renum Officio*, cap. xxix.

(81)

Beside the Frankfort edition of 1628, the same work appeared in Leyden, 1639; Padua, 1643; and Leyden, 1647. Also an English edition, The Anatomical Exercises of Dr. William Harvey, Professor of Physick, and Physician to the King's Majesty, concerning the motion of the *Heart* and *Blood*. With the Preface of *Zachariah Wood*, Physician of *Roterdam*. To which is added Dr. *James De Back* his discourse of the *Heart*, Physician in ordinary to the Town of *Roterdam*. London, 1653 (containing also the two letters addressed by Harvey to Riolan, in defence of the circulation). And the same in Latin with an additional index, Guilielmi Harveji, Doct. & Profess. Regii Exercitationes Anatomicæ De Motu Cordis & Sanguinis Circulatione. Cum duplici Indice Capitum & Rerum. Accessit Dissertatio de Corde Doct. Jacobi de Back, Urbis Roterodami Medici ordinarii. Roterodami, 1654.

These were the only editions which appeared during Harvey's life. Subsequently the last-named work was issued at Leyden, in 1736, and Glasgow, 1751. The London College of Physicians published, in 1766, a handsome folio edition of Harvey's works: *Guilielmi Harveii Opera Omnia: a Collegio Medicorum Londinensi edita;* MDCCLXVI. And lastly there is an English edition, translated from the Latin, with a life of the author, by Robert Willis, M.D., London, 1847.

(82)

It may seem surprising that Harvey should give so much consideration to the transfer of blood through the median septum, notwithstanding that seventy or eighty years had elapsed since Vesalius had declared against the porosity of the septum and Colombo had described the circulation through the lungs. But it has already been shown (page 131) how imperfectly these doctrines had gained foothold in general belief; and, in fact, the porosity of the septum was afterward maintained, as against Harvey, by no less a person than Riolan (*De Motu Circulatorio Sanguinis in Corde;* Londini, 1649; in the *Monitio ad Lectorem*, cap. i., p. 2, and cap. ii., p. 23).

(83)

In motu, & eo quo mouetur tempore, tria præ cæteris animaduertenda.

I. Quod erigitur cor, & in mucronem se sursum eleuat; sic vt illo tempore ferire pectus et foris sentiri pulsatio possit.

II. Vndique contrahi, magis vero secundum latera; ita vti minoris magnitudinis, & longiusculum, & collectum appareat.

III. Comprehensum manu cor eo quo mouetur tempore, duriusculum fieri, à tensione autem illa durities est, quemadmodum si quis lacertos in cubito manu comprehendens, dum mouent digitos, illos tendi, & magis renitentes fieri percipiat.

IV. Notandum insuper in piscibus, & frigidioribus sanguineis animalibus, vt serpentibus, ranis, &c., illo tempore, quo mouetur cor albidioris coloris esse, cum quiescit à motu coloris sanguinei saturum cerni.—*Harvey. De Motu Cordis et Sanguinis*, cap. ii.

(84)

Verum nemo amplius dubitare poterit, cum vsque in ventriculi cauitatem inflicto vulnere, singulis motibus, sive pulsationibus cordis, in ipsa tensione prosilire cum impetu foras contentum sanguinem viderit.—*Ibid.*, cap. ii.

(85)

Neque verum est similiter, quod vulgo creditur, cor vllo suo motu, aut distentione, sanguinem in ventriculos attrahere; dum enim mouetur, & tenditur, expellit: dum laxatur, & concidit, recipit sanguinem.—*Harvey. De Motu Cordis et Sanguinis*, cap. ii.

(86)

Et in mechanico illo artificio, quod sclopetis adaptant, vbi compressione alicuius ligulæ cadit silex, percutit chalybem et propellit, ignis elicitur, qui in puluerem cadit, ignitur puluis, interius prorepit, disploditur, euolat globulus, metam penetrat, & omnes isti motus proper celeritatem quasi in nictu oculi simul fieri apparent.—*Ibid.*, cap. v.

(87)

Motus itaq; cordis omnino ad hunc se habet modum, & vna actio cordis est ipsa sanguinis transfusio, & in extrema vsq; mediantibus arteriis propulsio, vt pulsus, quem nos sentimus in arteriis, nil nisi sanguinis à corde impulsus sit.—*Ibid.*, cap. v.

(88)

Et similis est conditio Embryonum pulmones habentium, dum adhuc pulmonibus non vtuntur, ac est eorum animalium, quæ pulmones non habent.—*Ibid.*, cap. vi.

(89)

Cur non iisdem argumentis de transitu sanguinis in adultis his per pulmones, fidem similem haberent, & cum Columbo peritissimo, doctissimoque Anatomico, idem assererent, et crederent, ex amplitudine, & fabrica vasorum pulmonum, & eo, quod arteria venosa, & similiter ventriculus, repleti sint semper sanguine, quem è venis huc venisse necesse est, & nulla alia, quam per pulmones semita, vt & ille, & nos ex ante dictis, & autopsia, aliisque argumentis palam esse existimemus.—*Harvey. De Motu Cordis et Sanguinis*, cap. vii.

(90)

Sed hoc peculiariter & luce clarius meridiana experiri licet. Vena caua partem inferiorem cordis subingreditur, exit arteria parte superiori: jam comprehensa vena caua vel tenaculis, vel digito & pollice, sanguinisq; cursu intercepto, per aliquod spatium infra cor, videbis expulsu, statim pene inaniri illam partem intra digitos & cor, sanguine exhausto à cordis pulsu, simul cor albidiori multo colore esse, etiam in dilatatione sua, & ob defectum sanguinis minus esse & languidius tandem pulsare, sic vt emori denique videatur. Contra statim soluta vena, color & magnitudo redeunt cordi; postea si relinquas venam, & arterias similiter per aliquam distantiam à corde ligaueris, vel compresseris, videbis contra illas turgere in parte comprehensa vehementer, & cor ultra modum distendi, purpureum colorem contrahere usque ad liuorem & tandem opprimi sanguine, sic vt suffocatum iri credas: soluto vero vinculo rursus ad naturalem constitutionem in colore, magnitudine, pulsu, redire.—*Ibid.*, cap. x.

(91)

In adultis his *per pulmonum cæcas porositates & vasorum eius oscilla*, tam ex Galeni verbis, quam ex ante dictis illud inquam fieri æque manifestum est.—*Harvey. De Motu Cordis et Sanguinis*, cap. vii.

Et quod in membris & extremitatibus sanguis, *vel per Anastomosin immediate, vel mediate per carnis porositates, vel vtroque modo* transire ab arteriis in venas.—*Ibid.*, cap. xi.

Signum est & sanguinem ab arteriis in venas & non contra, permeare, *& aut anastomosin vasorum esse, aut porositates carnis, & partium solidarum* peruias sanguini esse.—*Ibid.*, cap. xi.

Cum hæc confirmata sint omnia, & rationibus & ocularibus experimentis, quod sanguis per pulmones & cor, pulsu ventriculorum pertranseat, & in vniuersum corpus impellatur, & immittatur, *& ibi in venas & porositates carnis obrepat*, & per ipsas venas vndique de circumferentia ad centrum ab exiguis venis in maiores remeet.—*Ibid.*, cap. xiv.

(92)

Nusquam autem invenire potui vasa invicem, arterias scilicet cum venis, per orificia copulari: libenter ab aliis discerem, qui Galeno tantum adscribunt, ut ad verba ejus jurare ausi sint. Neque in jecore, liene, pulmonibus, renibus, aut aliquo viscere, est aliqua anastomosis: in quibus coctis, usque quo friabile totum redditur parenchyma et tanquam pulvis ab omnibus vasorum fibris excussus et acu detractus, omnes cujusvis divaricationis fibras, omnia capillamenta, evidenter cernere potuerim. Audacter igitur affirmare ausus sum, neque anastomosin esse vel venarum portae cum cava, arteriarum cum venis, aut pori choledochi capillarium ramulorum, qui per totam hepatis simam disperguntur, cum venis.—*Exercitatio Anatomica De Circulatione Sanguinis, ad J. Riolanum, Prima. Guilielmi Harveii Opera Omnia: a Collegio Medicorum Londinensi edita*, MDCCLXVI., p. 105.

(93)

Primerose refers to Galen's experiment of introducing a tube into an artery and tying the vessel over it, to show that the pulsific faculty of the arteries is transmitted through their walls; and illustrates it with a diagram.—*Exercitatio* xiv.

He speaks of the fact that the heart of a cold-blooded animal, when cut out and laid upon a table, will continue to beat, though it no longer receives or expels any blood.—*Animadversio in cap.* ii.

He mentions the double experiment of Galen, which consisted of tying, in different cases, the umbilical arteries and the umbilical vein of the living fœtus, to show the effect of these ligatures on the pulsation in the membranes.—*Animadversio in cap.* vi.; also *in cap.* ix.

He says that if an animal be killed and immediately opened, without allowing time for any considerable quantity of blood to be intercepted by the stoppage of respiration, the arteries will still be found containing but little blood in comparison with the veins.—*Animadversio in cap.* ix.

(94)

In favor of the circulation were; *Walaeus*, Epistola de Motu Sanguinis ad Thomam Bartholinum, Lugd. Bat., 1640; *Regius*, Spongia pro eluendis sordibus animadversionum Jacobi Primerosii in Theses de circulatione sanguinis, Lugd. Bat., 1640; *Ent*, Apologia pro circuitione sanguinis, qua respondetur Emilio Parisano, Medico Veneto, Londini, 1641; *Rolfink*, Dissertatio de Circulatione, Jena, 1642; and *Conringius*, De Sanguinis Generatione et Motu naturali, Helmstadt, 1643, Lugd. Bat., 1646.

Against it were; *Parisanus*, Lapis Lydius de Motu Cordis et Sanguinis, Venetiis, 1635; *Wormius*, De Circulatione dubia, &c., Epistola ad Thomam Bartholinum, Hafniæ, 1643; *Leichner*, De motu sanguinis Exercitatio Anti-Harveiana, Arnstadt, 1645; and *Licetus*, De Motu Sanguinis, &c., Utini, 1647.

(95)

Riolan is spoken of by his contemporaries with much respect, even when they are writing in opposition to his opinions. In the somewhat turgid phraseology of the time, Slegel calls him "Vir clarissimus," "Phœnix Anatomicorum," "magnus Riolanus noster," and "Princeps Anatomicorum"; Harvey addresses him in his published letters as "Medicum peritissimum," and "Anatomicorum coryphæum"; and Walaeus, in his letter to Bartholinus on the circulation, refers to him as "magnus ille Anatomicus."

(96)

The lymphatic vessels were noticed so nearly at the same time (1651) by Rudbeck in Leyden and Bartholinus in Copenhagen, that both these observers are usually credited with the merit of independent discovery.

(97)

In the *Malade imaginaire*, Doctor Diafoirus, in praising his son Thomas, says: "But above all, what pleases me in him is that he follows my example and attaches himself blindly to the opinions of our ancients; and that he would never have anything to do with the reasons and experiments of the pretended discoveries of our time touching the circulation of the blood, and other opinions of the same stamp." And Thomas, as a compliment to Angélique, presents her with a Thesis which he has composed, "*contre les circulateurs*." This play was first represented in 1673.

(98)

The magnifying instruments used by Malpighi consisted either of a double convex lens, or of two such lenses, one of them serving as an objective, the other as an eyepiece.

THE END.

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