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HISTORY OF THE DISCOVERY OF THE CIRCULATION OF THE BLOOD.*

In the minds of every one the circulation of the blood is invariably and justly associated with the name of Harvey. The discovery of the circulation, however, like that of all other great discoveries, was not made by Harvey alone. Indeed, the discovery of the circulation of the blood, in the widest acceptation of the term, cannot be attributed to any one person, age or country. With the name of Harvey must be associated those of Erasistratus, Galen, Servetus, Cæsalpinus, Malphigi, Aselli, Pecquet, Rudbeck, Bartholinus. The history of the circulation extends, therefore, over a period of 2000 years, from the epoch of the Egyptian Ptolemies to the latter part of the 17th century, and even, in some respects, to the present day. The general structure of the heart; its cavities; the play of its valves; the passage of the blood from its right side to the lungs, and back to its left side, thence through the arteries to all parts of the body; the valves in the veins; the flow of the venous blood toward the heart, had been demonstrated, in an isolated way, by this or that person, before Harvey's time; while it was not until after the appearance of his great work that the discovery of the capillaries made intelligible the manner in which the blood

* This essay was delivered as a lecture, at the Jefferson Medical College, December 10th, 1883, concluding a course on the circulation, and constitutes, with but little modification, the 25th chapter of a forthcoming work on Physiology, by the author.

passed from the arteries to the veins; and the demonstration of the lymphatics completed our otherwise imperfect knowledge of the circulation. If, however, the great generalizations as regards the circulation, just referred to, were made either before or after the time of Harvey, naturally, it might be asked what was there left for Harvey to discover? In what does the merit of his great work consist? In that he was the first to describe accurately the motions of the heart, and both the pulmonary and systemic circulations correctly. Without doubt Harvey was the first who described correctly the entire circulation of the blood, understanding by the word circulation the flowing of the blood from the heart to the lungs, back to the heart, thence through the arteries to the periphery, and from the periphery, through the veins, back to the heart. That is, the flowing of the blood in a circle. It must be remembered, however, that Harvey saw this circulation only in his mind's eye, as the capillaries or connecting links between the arterial and venous systems were not discovered by Malphigi until after Harvey's death. The history of the discovery of the circulation of the blood has been often told; but the subject is one of such interest, extending as it does over a very long period, illustrating so forcibly how slowly truth is attained, that fact after fact must be first established before any generalization can be arrived at; how the isolated, unconnected labors of generations finally culminate, in the hands of a genius, in a grand discovery; that I trust it will not be considered superfluous if I rapidly tell the story of the discovery of the circulation of the blood once more. Although no mention is made of bleeding in the Iliad, that encyclopædia of the knowledge possessed by the Greeks in Homer's day, yet there is no reason to doubt that Podalirius, who attended, as surgeon, the

hosts of Agamemnon, made use of this practice; as we learn from later sources[1] that, by bleeding the daughter of the King of Caria, he effected a cure, the reward of which was her hand in marriage, and as dowry, the Chersonesus. While the Greeks and the ancients generally were aware that the blood of man and animals coursed in a vast system of tubes, their knowledge of the circulation of the blood extended but a little beyond this. Indeed, their views on this subject were of the most imperfect or erroneous character. That the blood flowed in certain veins; that there were additional vessels erroneously called arteries, because they were supposed to contain air; that the heart was a hollow, muscular organ; constituted about all their knowledge of the circulation.[2] This is not to be wondered at, however, since the superstitious respect paid to their dead by the Greeks made dissection an impossibility, the little anatomical knowledge existing in the days of Hippocrates having been derived from

[1] *Stephani Byzantini, De Urbibus, Lug Bat.* 1694, *p.* 686. Syrna, urbs Cariæ, Condita est autem a Podalirio, Expulsum enim in Cariam a caprario euodam servatum, atque ad Damœthum Cariæ regem adductum, cujus filiam Syrnam ex tecto delapsam, ab eo sanatam esse. Sic vero aiunt animum despondente Damœtho, Podalirium ab utroque brachio sanguine ex tracto puellam sanitari restituisse Damœthum vero admiratum, ei pliam collocasse, ac dedisse Chersonesum.

Podalirius, exiled in Caria and preserved by a goatherd, was led to Damœthus, King of Caria, whose daughter Syrna had fallen from a roof, by him to be cured. Truly, they say that Damœthus was very despondent in his mind, but Podalirius having drawn blood from both arms, restored the girl to health. Damœthus was so much pleased that he gave him the Chersonesus and his daughter in marriage.

[2] Hippocrates' Opera Omnia, Lug Bat. 1665, p. 275. Euvres completes d'Hippocrate, Par E Littré, Tomes 8, Paris, 1839–1853. Introduction Tome 1, p. 241.

the rapid inspection of the viscera of animals sacrificed upon the altar on the occasion of some religious ceremony. Even Aristotle,[1] whose anatomical knowledge far exceeded that of Hippocrates, advanced but little our knowledge of the vascular system. Aristotle taught that the veins communicate with the heart; that vessels pass from the heart to the lungs, and that the heart and the veins are filled with blood. Such was the limited knowledge of the circulation of the blood as known to the most celebrated of the Greeks. A great advance, however, was soon to be made, not only in anatomy, but in all branches of science. The wonderful campaigns and victories of Alexander, Aristotle's patron, resulting in the conquering of Egypt and the establishing of the Macedonian dynasty of kings, and the building of Alexandria, not only revolutionized the political and social world, but influenced all branches of knowledge, in a way and to an extent that modern Europe is only now beginning to appreciate. Under the magnificent patronage of the Ptolemies, the Macedonian kings of Egypt, there arose at Alexandria that famous school, the Museum, a centre of learning for the organization and development of all kinds of knowledge, the like of which has never been seen since. There were associated under the hospitable roof of the Egyptian kings some of the most learned and wonderful men the world has ever seen. The astronomers, Hipparchus and Ptolemy; geometers like Euclid and Archimedes; the engineers and geographers, Apollonius, Erastosthenes; historians like Manetho; the theologian, Cyril; learned women like Hypatia; the celebrated anatomists and physicians, Herophilus and Erasistratus. For the practical study of astronomy there were placed beneath the Porch equinoctial and solstitial armils,

[1] *Αριστοτελους Περι Ζωων Ιστορια*, Lipsæ, 1869, Lib. III, Cap. II, III, IV.

quadrants, dioptras, astrolabes and meridian lines; a botanical garden offered opportunity to those who wished to study plants; a zoölogical menagerie offered facilities to those interested in the dissection of animals. The library, containing nearly a million volumes, was open daily to those desirous of making themselves acquainted with the knowledge of the day or of that of antiquity. Vast collections of all kinds of natural objects had been brought there, from every part of the known world, by the Macedonian conquerors, for the use and benefit of the student. At the Museum, in Alexandria, the student found everything that would assist, develop and refine the intellect—the calm, the leisure, the means of living and of study. The usages of that wonderful country, Egypt, where death perpetuates itself in a thousand embalmed forms, had from time immemorial familiarized the vulgar and uneducated with autopsies and dissections. The study of anatomy by the only means possible, the dissection of the dead body, was no longer regarded with superstitious horror and considered as sacrilege. Pliny tells us that those intelligent and magnificent princes, the Greek kings of Egypt, not only lavished their treasure in the interests of science, but personally attended the dissections that were daily conducted at the Museum. The Medical School of Alexandria gave to the world those famous anatomists, Herophilus and Erasistratus.[1] With them began the

[1] All that we know of these anatomists is derived from the accounts given of them by later writers, more particularly Galen, Ruffus and Celsus. Among the writings of Galen, especially, there are innumerable allusions to the discoveries made in anatomy by Herophilus. Among some of the most important of these may be mentioned the references that are found in Claudii Galeni opera omnia Venetiis, 1556, Tom. 1 and 2; De Different Pulsuum, Lib. IIII, Cap. 1 and 10; De Anat. Adminis., Lib. 6, Cap. 8 and 9, and Lib. 9, Cap. 1, 3 and 5; and the De Usu Pulsuum, Cap. 4. Reference to

study of the structure and use of the heart and its great blood vessels, by means of actual dissection.

The name of Herophilus ought to be familiar to all students of anatomy, as many parts of the human body, such as the Choroid Plexus, the Torcular Herophili, the Calamus Scriptorius, the Duodenum, etc., were first described by him. The most important contribution that he made to our knowledge of the vascular system was the demonstration of the isochronism of the pulsations of the arteries and of the beating of the heart, and of the latter being the cause of the former, a phenomena that had already been imperfectly referred to by Hippocrates and Aristotle. Herophilus noticed also the difference in the thickness of the walls of the arteries and of the veins, and described the vessels connecting the heart and the lungs, distinguishing the pulmonary artery from the pulmonary vein, designating the former as the arterial vein and the latter as the venous artery.

To Erasistratus, one of the most distinguished of the anatomists of the Alexandrian school, and one of the most celebrated physicians of antiquity, science is indebted for the discovery of

the same discoveries and views of Herophilus is made by Ruffus. Medicæ artis principes, 1567, Henricus Stephanus. Ruffii Ephesii Medici de appellationibus partium, Lib. 1, Cap. XVI, XXII, Lib. II, Cap. III, XVII. Celsus refers to the well known but not usually credited story of Herophilus and Erasistratus having dissected human criminals, in the enthusiasm engendered by their study of the human body. The passage will be found in Aurelii Cornelii Celsi de re medica libri octo, Præfatio in Med. art. princip. While both Ruffus and Celsus refer to Erasistratus, almost all our knowledge of his discoveries is based upon what is contained in Galen. Among the many passages in the different works of Galen referring to Erasistratus, I will only mention the following: Au Sanguis Natura, Cap. 2; De different puls., Book IIII, Cap. 10; De utilitate respirat., Cap. 1; De Hipp et Plato decret., Lib. VI, Cap. 6.—*Galenus edit. cit.*

the valves of the heart, and their function in the circulation. We have stated in a previous lecture that there is reason to believe that Erasistratus had seen the lacteals a dependence, so to speak, of the vascular system, even though he had misunderstood their use, and we shall see hereafter that he appears also to have distinguished the sensory from the motor nerves. While there is no doubt that the anatomists and physiologists of antiquity distinguished two kinds of vessels, arteries and veins, their very name, artery, from the Greek αηρ, air, and τηρεω, I carry, conclusively proves how absolutely ignorant they were of the true functions of these vessels. Hippocrates, Aristotle, and more especially Erasistratus, believed that the arteries, as their name implies, carried air. This error was due, no doubt, to the fact that when a dead body is opened the arteries are usually found empty; and to the theory that the air in these vessels came, originally, from the trachea, hence the name of tracheal artery, by which it is designated by the French, even at the present day. Erasistratus[1] supposed the air passed from the trachea into the pulmonary veins (his venous artery), from there to the left side of the heart, and thence, by the arteries, to all parts of the body. Substitute for the air oxygen, and for his venous artery pulmonary capillaries, and the much-abused theory of Erasistratus becomes the modern one of respiration. Although during the four centuries that followed the brilliant epoch of the Alexan-

[1] *Galenus edit. cit.* De utilitate respirationis, Cap. 1. "Quænam est utilitas respirationis . . . . Nam animæ ipsius generatio est . . . . An innati caloris ventilatio ac refrigeratio . . . . Aut horum quidem nihil est verum arteriarum expletionis gratia respiramus velut Erasistratus putat."

Galenus edit. cit. An Sanguis in arteriis, Cap. 2. "Enim sicuti Erasistratus putat ex ambieute nos ære intra corpus assumpto primo in pulmonem deinde in cor ortas que ab eo arterias."

drian school just described, dissection had gradually fallen into disuse, nevertheless the most famous anatomist of antiquity, Galen, learned his anatomy in Egypt, where he devoted many years to anatomical studies. His dissections, however, appear to have been limited to animals. By ligating in a living animal, an artery in two places, and opening the vessel between the ligatures, Galen[1] demonstrated that the vessel contained blood. Thus, by an experiment upon a living animal, a vivisection, the first great source of error, that of supposing that the arteries contained air, was removed, the true nature of an artery demonstrated, and the modern theory of the circulation of the blood made possible. Too much importance cannot be attached to this cardinal experiment of Galen. It is evident that as long as it was believed that the veins alone carried blood, and that the arteries only contained air, the discovery of the circulation was an impossibility.

For 1300 years, in anatomical and physiological matters, the authority of Galen was supreme. With the truths discovered by this most deservedly famous physician, were perpetuated errors, among which was Galen's theory that the air inspired did not enter the body to any extent, as Erasistratus supposed, but was at once rejected after having performed its office, which was that of cooling the body, and that the cavity of the right ventricle of the heart communicated with that of the left ventricle by

[1] *Galenus edit. cit. an sanguis in arteriis natura contineatur Cap.* 6.

"Nam ubi funiculo dissectam arteriam utrinque ligavimus et quod in medio comprehensum fuerat incidimus sanguine plenam ipsam esse monstravimus."

[2] *Galenus edit. cit. an sanguis &c., Cap.* 6.

"Qui cor inquiunt non æris substantiam exposcere sed frigidetatem solum modo qua recreare desiderat atque hunc esse respirationis usum."

means of holes in the septum.[1] It is true that no one had ever seen these holes in the septum, separating the ventricle; even Galen himself did not claim that he actually saw them; but the theory in Galen's time, and many a day afterwards, was, that the spirituous blood of the left ventricle[2] must be mixed with the coarser blood of the right ventricle, that the latter should fulfill its function in nutrition.[3] Now the only way that theory could account for this mixing of these two kinds of blood was on the supposition that the septum of the ventricle was perforated with holes, through which part of the blood passed from one ventricle to the other, the rest of the blood passing through the pulmonary artery to the lungs.

Men saw, or believed they saw, what theory demanded they ought to see. As has been too often the case, as the history of science teaches us, the theory did not follow from the facts, but the facts were made to suit the theory. Further, when it is remembered that for sixteen centuries, during the period extending from the epoch of the Alexandrian Museum to that of the School of Salerno, in 1224,[4] or more probably to that of Mundini, in 1306,[5] the human body had never been dissected, it is not to be wondered at that the grossest ignorance of anatomy

[1] *Galenus Edit. cit. De usu partium, Lib*, 6, *Cap.* 17. "Quæ igitur in corde apparet foramina ad ipsius potissimum medium septum prædictæ communitatis gratia extiterunt."

[2] *De usu part., Lib.* 6, *Cap.* 17. "Spiritus animalis exhalatio quædam est sanguinis benigni."

[3] *De usu part., Lib.* 6, *Cap.* 16. "Atquæ arteriæ quidem tenuem ac purum et vaporosum participat sanguinem venæ autem paucum, eundam que caglinosum ærem."

[4] Hæser, Geschichte der Medecin, Jena, 1875, pp. 733–738. Corradi, Rendiconde del R. Institut. Lombardo, Ser. ii, Vol. vi.

[5] Hyrtl, Das Arabische und Hebraische in der Anatomie, Wien, 1879, p. xi.

should have universally prevailed. The horror with which dissection was regarded, and the limited number of subjects obtainable for study, will be appreciated from the fact that Mundini, who was Professor of Anatomy at Bologna during the latter part of the 13th and beginning of the 14th century, had dissected in eleven years only three human bodies. Berenger de Carpi, who also occupied the Chair of Anatomy in Bologna a century later, had better opportunities of study than Mundini, whose works he commentated, he having dissected a hundred bodies; and yet the authority of Galen had such weight with de Carpi, that he states that there are certainly holes in the septum separating the ventricles. He adds, however, as if he had an uneasy suspicion as to the truth of the statement, that these holes are seen in man with great difficulty.[1]

A short time, however, after the publication of De Carpi's work, viz., in 1553, there appeared the Christianismi Restitutio of the Spaniard, Michael Servetus, whose career reads rather like that of the hero in some romance than of a real historical personage. Educated for the priesthood at Saragossa, relinquishing such studies for that of the law, at Toulouse; accompanying, as secretary, Quintana, Confessor to Charles V, upon the occasion of the imperial coronation at Bologna; and going afterwards to the Diet of Augsburg; giving up the prospect of a diplomatic career for that of a theologian; leaving Switzerland and changing his name to Villanovus, to avoid persecution; supporting himself as a proof-reader and editor of learned books while a

[1] *Berenger de Carpi.* Commentarii cum amplissismus additionibus super anatomia Mundini. *Bologna* 1521 *p. cccxli.*

Ista substantia dividit ventrem dextrem a sinistro et in ista substantia sunt certe porositates—sed in homine cum maxima difficultate videntur.

student of medicine in Paris; receiving his degree of doctor in medicine; writing works on medical subjects, and practicing medicine with great success for a number of years; returning to the study of theology again, his career of usefulness is suddenly cut short by death at the stake; Servetus, as is well known, being burned alive, in 1553, at Geneva, for heresy, as the author of the Christianismi Restitutio. This work, as its name implies, is a theological treatise, but is also of the greatest interest to the physiologist, as in discussing the nature of the vital spirit, and the manner in which it is elaborated, Servetus describes the flow of the blood from the right ventricle of the heart, by the pulmonary artery, through the lungs, and by the pulmonary veins to the left ventricle; distinctly stating that the blood does not pass from the right ventricle to the left through the septum of the heart, as is commonly believed, but by a long passage through the lungs, from the right ventricle, and that it is in the lungs that the blood is agitated, prepared and changes its color, thence passing to the left ventricle by the pulmonary veins. Servetus was not only the first to describe, therefore, the flow of the blood from the right side of the heart, through the lungs, to the left, and the imperviousness of the septum of the heart, but was also the first to point out the place where the venous was changed into arterial blood, the significance of which discovery was neither understood nor appreciated for more than a century afterwards. Further, Servetus adds that the left ventricle is not sufficiently capacious for so copious a mixture, nor will it suffice for the elaboration of the color; and that the septum is neither fit for the communication nor the elaboration of the blood, even if any may exude through it. Servetus evidently does not consider that any blood passes through the

septum of the heart, for he most distinctly says that none does so, and in confirmation of his view adds that even if any blood did pass through the septum, the left ventricle is not adapted to its elaboration. That Servetus did not hold the view of Galen, of part of the blood passing through the pulmonary artery and part through the septum, is evident from what Servetus says, that if any one compares his views with Galen's (and no one understood Galen better than Servetus), he will perceive clearly the truth not observed by Galen himself. As comparatively few persons have the opportunity of examining an original copy of the Christianismi Restitutio of Servetus, and as the passage in that work to which I have referred is often imperfectly or incorrectly quoted, I will give it exactly, as I copied it from the original copy in the National Library, at Paris. For this privilege I am indebted to Mr. George A. Barringer, one of the librarians of that noble institution, who also afforded me the opportunity of comparing the Nuremberg reprint, of 1791, of the Restitutio, with the original copy of 1553; as well as of consulting many rare and interesting works on the circulation. The celebrated passage upon the pulmonary circulation, in the Restitutio, is found in Liber Quintus, De Trinitate Divina, In quo agitur de Spiritus Sancto, p. 170, and is as follows:—

"Ad quem rem est prius intelligenda substantialis generatio ipsius vitalis spiritus, qui ex ære inspirato et subtillissimo sanguine componitur et nutritur. Vitalis spiritus in sinistro cordis ventriculo suam originem habet, juvantibus maxime pulmonibus ad ipsius generationem. Est spiritus tenuis, caloris vi elaboratus, flavo colore, ignea potentia, ut sit quasi ex puriori sanguine lucidus vapor, substantiam in se continens aquæ, æris et ignis. Generatur ex facta in pulmonibus mixtione inspirati æris 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, flavis efficitur, et a vena arteriosa in arteriam venosam transfunditur. Deinde in ipsa arteria venosa inspiratio æri miscetur, expiratione a fulgine repurgatur. Atque ita tandem a sinistro cordis ventriculo totum mixtum per diastolem attrahitur apta supellex, ut fiat spiritus vitalis. Quod ita per pulmones fiat communicatio et præparatio, docet conjunctio varia et communicatio venæ arteriosæ cum arteria venosa in pulmonibus. Confirmat hoc magnitudo insignis venæ arteriosæ, qua nec talis, nec tanta facta esset, nec tantam a corde ipso vim purissimi sanguinis in pulmones emitteret, ob solum eorum nutrimentum, nec cor pulmonibus hoc ratione serviret; cum prasertim antea in embryone solerent pulmones ipsi aliunde nutriri, ob membranulas illas, seu valvulas cordis usque ad horam nativitalis nondum opertas, ut docet Galenus, Ergo ad alium usum effunditur sanguis a corde in pulmones hora ipsa nativitatis, et tam copiosus. Item a pulmonibus ad cor non simplex aer, sed mixtus sanguine mittitur per arteriam venosam, ergo in pulmonibus fit mixtio. Flavus ille color a pulmonibus datur sanguine spirituoso, non a corde. In sinistro cordis ventriculo non est locus capax tantæ et tam copiosæ mixtionis, nec ad flavum elaboratio illa sufficiens, Demum, paries ille medius, cum sit vasorum et facultatem 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 cavam 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. vi, et vii, de usu partium, veritatem penitus intelliget, ab ipso Galeno non animadversam. Ille itaque spiritus vitalis a sinistro cordis ventriculo in arterias tolius corporis deinde transfunditur." Which may be literally, if not elegantly, translated as follows:—

"For which purpose the substantial generation of the vital spirit itself is first to be understood, which is composed of and nourished by the inspired air and most subtile blood. The vital spirit has its origin in the left ventricle of the heart, the lungs aiding, to the highest degree, in its generation. The spirit is subtile, elaborated by the force of heat, of a yellowish color, with the power of fire, to the end that it may be, as it were, a bright vapor from the purer blood, containing in itself the substance of water, air, and of fire. It is generated, in fact, in the lungs, with the mixture of inspired air with the elaborated, subtile blood, which the right ventricle of the heart communicates to the left. Yet this communication is made, not by the middle wall of the heart, as is commonly believed, but the subtile blood is driven, by a great plan or device, from the right ventricle of the heart, by the long passage through the lungs; is prepared in the lungs; the yellow color is made, and it is poured out from the arterial vein (vena arteriosa or pulmonary artery) into the venous artery (arteria venosa or pulmonary vein); there is mixed in the venous artery itself with the inspired air; is purged by expiration of its fuliginous matter; and so, at length, the whole mixture is attracted by the diastole from the left ventricle of the heart, a fit stuff out of which to make vital spirit. The various connection and communication of the arterial vein with the venous artery teaches that the communication and preparation is made by the lungs in this manner. The remark-

able size of the pulmonary artery confirms this, which would be neither made in such a way nor so large, nor would there be emitted so great a mass of blood from the heart itself into the lungs, if for the nourishment of these alone, nor would the heart serve the lungs in this manner, since especially before, in embryo, the lungs themselves are accustomed to be nourished from elsewhere, on account of those little membranes, or valves of the heart, not yet being open until the hour of birth, as Galen teaches. Therefore the blood is poured forth, and so copiously, from the heart into the lungs at the hour of birth, for another use. The air also is sent from the lungs to the heart by the venous artery, not pure, but mixed with blood; therefore the mixture is made in the lungs. That yellow color is given to the blood by the lungs, not by the heart. The space in the left ventricle is not capable of holding so great and so capacious a mixture, nor is sufficient for that elaboration of color. Finally, that middle wall, as it is wanting in vessels and power, is not fit for that communication and elaboration, even if some might sweat through. By the same plan by which the transfusion is made from the vena porta to the vena cava, with reference to the blood, so the transfusion from the arterial vein to the venous artery is made in the lungs, with reference to the spirit. If any one compares this with that which Galen writes, Lib. VI, et VII, on the use of the parts, he easily perceives the truth, not observed by Galen himself. And so the vital spirit from the left ventricle of the heart is thence poured out into the arteries of the whole body."[1]

[1] I take this opportunity of acknowledging my indebtedness to Mr. John Swaby, who on this occasion, as well as on numerous others, has given me the benefit of his critical knowledge of the Greek and Latin languages.

The Christianismi Restitutio is a very rare work. At the present moment there are, indeed, only three original copies known to exist—one in the National Library at Paris, one in the Imperial Library at Vienna, and one in the Library of the University of Edinburgh. The copy in Paris probably belonged to Colladon, Calvin's lawyer, since his name is in it, and was in the possession of the celebrated Dr. Mead, of London, in the early part of the eighteenth century, from whose hands it passed successively through those of De Boze, De Cotte, Gaignat, la Vaillere, finally becoming the property of the National Library. There is not the slightest reason to suppose that the Paris copy of the Restitutio was ever in the flames that enveloped its author, as is picturesquely described by Flourens,[1] the blackness on the pages being due, not to fire, but possibly to dampness.[2]

It is usually supposed that the Paris copy of the Restitutio, once in the possession of Dr. Mead is the identical one that disappeared from the library of the Landgrave of Hesse Cassel. However that may be, there can be no doubt that there was a copy of the Restitutio in the Library at Hesse, in the 17th century, as it was from this copy that Wotton obtained the quotation (though he never saw the original) that is to be found on the margin of page 230 of his "Reflections upon Ancient and Modern Learning, the second edition, with large additions, London, 1697." In referring to this quotation, p. 230, Wotton simply observes that he got it from Mr. Charles Bernard, who "had it from a learned friend of his, who had himself copied it from Servetus." In the postscript of the "Reflections" Wotton,

[1] Histoiré de la deconverte de la Circulation du Sang, Paris, 1857, p. 155.

[2] Henri Tollin, Die Entdeckung des Blutkreislaufs, durch Michael Servet. Jena, 1876, p. 69.

however, at page XXV, states that the quotation from Servetus "was copied long ago, by that worthy member of the Royal Society, Mr. Abraham Hill, from whom Mr. Bernard had it. My Lord Bishop of Norwich, whose incomparable library contains everything that is rare and excellent, did me the honor to show it me. His manuscript copy is a transcript of that printed one which is preserved in the Landgrave of Hesse's library, at Cassel, the very book that was perused by Sandius, who gives an account of it in his Bibliotheca Anti-Trinitariorum." It is very evident, therefore, that Wotton was not the first, as is often said, to make known to the republic of letters the existence of a copy of the Christianismi Restitutio of Servetus, since he states that Sandius gives an account of it. The reference of Sandius to the Christianismi Restitutio mentioned by Wotton, is to be found on p. 14 of the Bibliotheca Anti-Trinitariorum Opus Posthumum Christophori Chr. Sandii Freistadii, 1684, and is as follows: "Asservatur unum ejus exemplar in Bibliotheca Illustrissimi Principis Hassiæ quæ est Casselis." Sandius, in this article, gives a short account of the life, as well as of the works, of Servetus. I may mention here, incidentally, that the quotation from Servetus, as given by Wotton, differs a little from the text of the Paris copy. This may be due to carelessness on the part of whoever made the transcript. Curiously enough, the Vienna copy of the Restitutio was once in London, as well as the Paris one; Markos Ivanayi, a Transylvania gentleman, residing in London in 1665, possessing it. He afterwards gave it to the congregation at Claudiopolis, who presented it, through their Superior, to Count Teleki de Izek, who presented it, in turn, to Joseph Second, Emperor of Austria. It was in this way that the library in Vienna came to have a copy. It was

from this copy that the Nuremberg reprint of 1791 was made. The third copy, that in the Edinburgh University library, is imperfect, unfortunately wanting the title-page and first sixteen pages. Otherwise the copy is in good condition. Of its history nothing is known, except that it was presented by Dr. George Douglas, in 1695.

It is usually stated that of the thousand copies of the Christianismi Restitutio that were known to have been printed, four or five only escaped destruction, including the three that are now known to exist, and as these three copies for a long time remained unknown, the inference is drawn that the Christianismi Restitutio did not influence, in any way, the progress of Physiology. It must not be forgotten, however, that in the distribution of the Restitutio, two hundred copies were sent to Frankfort, the headquarters of the book trade, and that it was not until several months afterwards that the existence of these copies became known to Calvin, who requested to have them destroyed. To express, in Geneva, a wish to have two hundred copies of a book destroyed in Frankfort, months after the books had arrived there, is a different matter from the actual destruction of the books, and it has always been a matter of doubt with me as to whether all of those two hundred Frankfort copies were destroyed. Indeed, it would be worth while ransacking the European libraries with a view of learning if there are still existing any undescribed copies of the Restitutio. As a matter of fact, it was in this way that the public learned of the existence of the Edinburgh copy, Prof. Turner requesting Mr. Small, the librarian, to look if there was a copy in the library of the University of Edinburgh.[1] It is quite natural to suppose that

[1] Athenæum, London, 1878.

both the enemies and friends of Servetus should wish to obtain a copy of the Restitutio, for the writing of which the author was being tried for his life at Geneva. All Switzerland was alive with excitement in reference to Servetus, both on theological and political grounds. The interest in his views and his fate extended to both Germany and Italy. Just in proportion, therefore, as efforts were made to suppress the work, so would the desire to obtain it be increased, and I can hardly suppose that, under the circumstances, the Frankfort bookseller would not have disposed of some copies, particularly if it could have been managed quietly and with great profit, especially before the intimation had been received that it would be safer to destroy the books rather than sell them. Even if a copy of the Restitutio was not obtainable in France, Switzerland, Germany, or Italy, it cannot be doubted but that the views of Servetus were well known to the learned men of those countries, since Servetus had sent manuscript copies of his work, not only to Calvin, in Geneva, but also to Melancthon, in Germany, and even to Curio[1] in Padua, Italy; and it is not likely, either, that his old friends, who permitted him to escape from France, would not have retained some memento of their physician. It is hardly to be supposed that the possessors of these manuscripts or copies of the Restitutio itself never showed them to any one. So far from the views of Servetus not being generally known to the learned men of the day, the state of public opinion, as expressed shortly after the death of Servetus, seems to me to prove that exactly the opposite was the case, and that of all places, Padua would be the one where new views upon the circulation of the

[1] Tollin, Colombo Matteo Realdo, in Pfluger's Archiv, Band 27, 1880, pp. 278 and 279.

blood would attract the greatest attention. To say the least, it is certainly a curious coincidence that the great advance in our knowledge of the structure of the heart and the passage of the blood through it, should have been made by Vesalius, Colombo, Cæsalpinus, etc., within a few years after the printing of the Christianismi Restitutio of Servetus.

In the year 1555, two years after the printing of the Christianismi Restitutio, there appeared the second edition of the magnificent Anatomy of Vesalius, which differed in many important respects from the first edition of 1543; among others, as regards the description of the heart. In the 1555 edition, Vesalius begins by saying that, influenced by the views of Galen, he considered that the blood passed from the right to the left ventricle of the heart, through the septum, by means of the pores. He immediately adds, however, that the septum of the heart is as thick, dense and compact as the rest of the heart, and that not the smallest quantity of blood passes through the septum. There can be no doubt that Vesalius held that the septum of the heart was imperforate, in this (the 1555) edition, but the passage in which he maintains this view is not to be found in the 1543 edition; and yet, in all of the accounts of the history of the circulation with which I am familiar, that of Tollin[1] excepted, the views of Vesalius in reference to the imperviousness of the septum of the heart (printed in 1555),[2] are said to have preceded

[1] Die Entdeckung des Blutkreislaufs, Jena, 1876, p. 26.

[2] *Andreæ Vesalii, De Humani corporis fabrica Libri septem, Basileæ*, 1555. "Qui aptius impetu post modum per arterias ferri possit reddens. Maxima portione per ventriculorum cordis septi poros in sinistrum ventriculum desudare sinit, p. 743.

In cordis itaque constructionis ratione, ipsius que partium usu recensendis, magna ex parte. Galeni dogmatibus sermonem accommodavi. * * * *

those of Servetus (printed in 1553). The only way in which I can account for this error is by supposing that the historians of the circulation, in quoting Vesalius, have made use of the 1555 or 1725 editions, and not that of 1543. Certainly Servetus did not learn his anatomy from Vesalius, since they were at the same time prosectors for Guntherus, Professor of Anatomy in the Medical School of Paris; and as to Servetus' knowledge of practical anatomy, there can be no doubt, Guntherus testifying to that.[1] On the other hand, Vesalius was probably entirely ignorant of what his former associate in the dissecting-room had published about the heart. Thus Ceradini (Difesa della mia Memoria Genova, 1870, pp. 126–130), while admitting that it is in the 1555 edition of his Anatomy that Vesalius describes the imperviousness of the septum of the heart, nevertheless claims that Vesalius had discovered this in 1546. Ceradini supports his view by reference to the letter "De chynæ radice,"

* * * Haud enim leviter studiosis expendendum est ventriculorum cord's interstitium aut septum ipsum que sinistri ventriculi dextrum latus quod æque crassum compactum que ac densum est, atque reliqua cordis pars sinistrum ventriculum complectens adeo ut ignorem (quicquid etiam de foveis hac in sede commenter & vena portæ ex ventriculo & intestinis suctionis non sim immemor) qui per septi illius substantiam ex dextro ventriculo in sinistrum vel minimum quid sanguinis assumi possit præcipui quum tam patentibus orificis vasa cordis in suorum ventriculorum amplitudinem dehiscant ut modo taceam verum venæ cavæ ex corde progressem, p. 746.

[1] *Haller Bibliotheca Anatomica, Tomus I, Tiguri*, 1774. Verum &c. ipse in præfatione fateter, se Vesalio et Serveto in administrationibus usum esse, eorum que ope partes corporis humani a se ostensas &c. vas a spermatica inventa iterum Vesalio tribuit, p. 174.

In villa nova Arragoniæ civitate natus passim patriæ, nomen gessit, æris ingenii vir et anatomes minime imperitus quem J. Guintherus secundo a Vesalio loco inter eos discipulos numerat qui sibi adsgumento fuerunt, p. 204.

written by Vesalius, in 1546 to Roelants, and to the Apologia Francisci Putei pro Galeno in anatome examen, Venetiis, 1564, written by Vesalius, under the name of Gabriele Cuneo, one of his disciples. Both of these works are to be found in Vesalius' Opera Omnia, Lug Bat. 1725, Tomus Secundus, pp, 569, 864. Admitting, as Ceradini thinks, that these two works, taken together, prove that Vesalius had demonstrated to his colleagues the imperviousness of the septum upon the cadaver, at Pisa, in 1546 (before he left Italy to establish himself at the court of Charles V), it follows that Vesalius was not indebted to Servetus for the demonstration, but, inasmuch as his description was not printed till 1555, the priority of the discovery must be accorded to Servetus in 1553.

While to my mind there is no doubt that the pulmonary circulation was correctly described by Servetus, beyond statements like that of the blood being transmitted by the left ventricle to the aorta, and thence through the arteries to the whole system, and of the blood flowing from the vena porta through the liver to the hepatic vein, etc., I can find nothing in his work to warrant the idea that Servetus had any idea of the so-called systemic or general circulation. Further, it is not to be supposed that Servetus understood the exact manner in which the blood passed from the pulmonary arteries to the veins, since the capillaries were not discovered by Malphigi for more than a century afterwards.

Six years after the death of Servetus, that is, in 1559, the pulmonary circulation was re-described by Colombo, who taught anatomy at Padua, Pisa and Rome. In a work on anatomical subjects, Colombo, in speaking of the heart, observes that between the ventricles a septum is present, through which almost every

one believes that the blood passes from the right ventricle of the heart to the left, but that really the blood goes through the pulmonary artery to the lungs, and is then carried, with the air, by the pulmonary vein, to the left ventricle of the heart, and that no one had previously observed or described this.[1] Colombo, however, is evidently wrong when he says no one had previously observed or described this. It is possible that Colombo was ignorant of what Servetus had written in his Christianismi Restitutio, but it certainly appears to me very extraordinary, if such was the case, for Colombo was the pupil of Vesalius, and taught, as prosector and professor, for years, in Padua, the very city where we have seen Servetus had sent one of the manuscript copies of his work, and where his views were well known. To suppose that Colombo was ignorant of the discovery of the pulmonary circulation by Servetus, seems to me to be almost incredible. There was one very good reason, however,[2] for Colombo not mentioning Servetus, if he was acquainted with his views; and that was the fear of being burned. Colombo ran no risk in describing the pulmonary circulation, but had he given Servetus as his authority he would have at once been accused of heresy, on the ground that if he regarded Servetus as an

[1] *Realdi Columbi Cremonensis in alino Gymnaso Romano Anatomici celeberimmi De Re Anatomica, Libri xv, Venetiis*, 1559; *Lib. vii, De corde et Arteriis, p.* 177. Inter nos ventriculos septum adest, per quod fere omnes existimant sanguini a dextro ventriculo ad sinistrum, aditum patefieri ut fiat facilius in transitu ob vitalium spiritum generationem tenuem reddi sed longa errant via nam sanguis per arteriosam venam ad pulmonem fertur, ubique attenuater deinde cum aere una per arteriam venalem ad sinistrum cordis ventriculis defertur quod nemo hactenus aut animadvertit aut scriptum reliquit licet maxime fit ab omnibus animadvertendem.

[2] Tollin Die Entdeckung des Blutkreislaufs, etc., Jena, 1876, p. 39.

authority in physiological matters, he would respect him equally in reference to theological ones. Whether Colombo was acquainted with the writings or the views of Servetus may be a question, but there can be no doubt that he understood and described the pulmonary circulation. This able anatomist, however, held entirely erroneous views as regards the general or systemic circulation, for, in speaking of the liver and veins, in the same work that we have just referred to, he distinctly states that the liver is the head, the fountain, the origin of all the veins.[1] It is evident that one who held, with Galen, that the veins originated in the liver, the venous blood being transmitted thence to the periphery, could have no idea of the general circulation.

In 1571, eighteen years after the death of Servetus, there appeared the Quæstionum Peripateticarum of Cæsalpinus, one of the most distinguished of the many celebrated men that Italy produced in the 16th century. Cæsalpinus taught medicine at Pisa, and was afterwards physician to Pope Clement VIII, at Rome, and was as distinguished a botanist as a physician, being the first to classify plants according to a natural method, and may be justly regarded as the father of vegetable anatomy. It is an interesting fact that in this work, in which the pulmonary circulation is described, for the first time in the literature of medicine the term circulation of the blood is used, Cæsalpinus saying[2] that this circulation of the blood from the right ventricle

[1] *De jecore et venis, p.* 164, *op. cit.* Aliqui credidere ibi generavi spiritus naturalis quam tamen sententia non approbo membrum est sánguini facationi dicatum neg enim sanguis alibi gignitur quicquid de corde scripserit Peripateticoni princeps Aristol. Est igitur jecur omnium venarum caput fons origo radix huius cava parte vena oritur selechia a Græcis quam portam Latinii dicunt.

[2] *Andrea Cæsalpini Aretini Quæstionum Peripateticarum, Venetiis,* 1593,

of the heart, by the lungs, to the left ventricle of the same, agrees best with what appears from dissection. One can hardly believe that such a learned man as Cæsalpinus was unaware of the views of Servetus or Colombo; certainly, at least, of the existence of the De re Anatomica, published so recently as 1559, and by an anatomist who taught in the neighboring city of Padua; and yet he mentions neither.

If, however, Cæsalpinus was indebted to Servetus for his views of the pulmonary circulation, he had the same good reason as Colombo for not mentioning him, and no particular reason for referring to Colombo. It is strange, however, that if Cæsalpinus' views upon the pulmonary circulation were derived from either the works of Servetus or Colombo, he should have held, with Galen, as he undoubtedly did,[1] that the septum of the heart was pervious, part of the blood passing directly from the right to the left ventricle, which both Servetus and Colombo showed was not the case. Had Cæsalpinus published nothing more than his Quæstiorum Peripateticarium, there would have been no

Lib. v, Quæstio iiii, p. 125. Id circo pulmo per venam arteriis similem ex dextro cordis ventriculo semilem pauries sanguinem eumque per anastomosum arteriæ venali reddens que in sinistra cordis ventriculum rendit transmissio internam aere frigido per asperæ arteriæ canales qui juxta arteriam venalem protenditur non tamen osculis communicantes ut putant Galenus solo tacto imperat. Huic sanguinis circulatione ex dextra cordis ventriculo per pulmones in sinistrum ejus dem ventriculem optime respondent ex quæ a dissectione apparet. Cum enim servere oporteret in corde sanguine ut fieret alimenti perfectio primo quidem in dextro ventriculo in quo crassior adhuc continetur sanguis, deinde autem in sinistro ubi syncerior jam sanguis est, partim per medium septum, partim per medios pulmones refrigerationis gratia ex dextro in sinistrum transmittitur.

[1] *Op. cit. p.* 126. Sanguis partem per medium septum partem per medios pulmones . . . . ex dextro in sinistro ventriculum cordis transmittitur.

necessity for my referring to that philosopher in connection with the history of the discovery of the circulation of the blood. Twelve years afterwards (1583), however, the De Plantis, by the same author, appeared, and this work has the greatest interest for us, as for the first time the general or systemic circulation, with the exception of the capillaries, is described, though it must be admitted that the description is very brief, and supported by little or no experimental evidence. In this work Cæsalpinus distinctly says[1] that the food is carried by the veins to the heart, and thence, by means of the arteries, is distributed to all parts of the body. Cæsalpinus not only understood the way in which nutriment is distributed throughout the economy, but, with the exception of the capillaries, the manner in which the blood flows through the system. For in his Quæstionum Medicarum (p. 234), Cæsalpinus calls attention to the fact that when the veins in the neck are compressed the swelling of the veins is between the brain and ligature, not between the ligature and the heart, and draws the conclusion that just the opposite ought to happen, that is, the swelling ought to be between the ligature and the heart, if the motion of the blood in the veins is from the heart and other viscera to the periphery of the system, as was the general opinion at that time. Cæsalpinus continues, in the same page, by saying that there is a perpetual motion of the blood from the vena cava, through the heart and lungs, to the aorta, and that the arteries communicate with the veins, by

[1] *De Plantis Libri. xvi Florentiæ*, 1583, *Lib.* 1, *Cap*, *ii*, *p.* 3. 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 ultima perfectione per arterias in universum corpus distribue agente spiritu qui in eodem alimento in corde gignitur.

what are called anastomoses; that the blood flows to the upper parts and returns, Euripus-like, to the lower ones, is perfectly evident, both when one is asleep and awake, and that this motion is not obscure in any part of the body when you experiment by binding veins or occluding them in any other manner. The above distinct, concise statements appear to me to prove that Cæsalpinus understood the systemic circulation, as far as was possible for one who had never seen the capillaries; as regards the pulmonary circulation he undoubtedly also states that the blood passed from the right side of the heart to the left, by the lungs; but as we have seen that, in the Quæstionum Peripateticarum, he says that part of the blood passes through the septum, and as he does not contradict this statement, but refers to this work as containing his views, he could only have understood the pulmonary circulation imperfectly. By most of those who have written on the discovery of the circulation, a very different interpretation, however, is offered of the views of Cæsalpinus from that just given. By such, it is stated that Cæsalpinus held that there was a to-and-fro motion of the blood in the veins, Euripus-like; that the arteries communicated with the veins only during sleep; that the blood only irrigated the tissues, but did not circulate through them, etc. If these are the views of Cæsalpinus, then he certainly did not understand the circulation in any part of its course.

In order that the reader may judge for himself, as to what the views of Cæsalpinus really were, I will give the passage from his Quæstionum Medicarum,—to which I have referred, both in the original and in a translation—and will say but a word further concerning it.

Andreæ Cæsalpini Aretini, Quæstionum Medicanum, Libri II,

Venetiis, 1593, *Liber Secundus, Quæst. xvii, pp.* 233 *et* 234.—"Ex hac vero positione non minum aliquando solum soporem gigni ex venarum apprehensione in collo, aliquando etiam suffocationem. Necesse enim est ex ea apprehensione virtutem cordis non communicari cerebro, ideo tolli sensum et motum voluntarium toti corpori, at non est necesse oppleri adeo pulmonem, ut suffocetur. Sed illud speculatione dignum videtur, propter quid ex vinculo intumescunt venæ ultra locum apprehensum, non citra; quod experimento sciunt qui venam secant, vinculum enim adhibent citra locum sectionis non ultra, quia tument venæ ultra vinculum non citra. Debuisset autem opposito modo contingere, si motus sanguinis et spiritus a visceribus fit in totum corpus—intercepto suim meatu non ultro datur progressus, tumor igitur venarum citra vinculum debuisset fieri. Au soliutur dubitatio ex eo quod scribit Aristoteles de som Cap. 3, ubi inquit Necesse enim quod evaporatur aliquo usque impelli, deinde converti &c. permutari sicut Euripi, calidum enim cuiusque animalium ad superiora natum est ferri, cum autem in superioribus locis fuerit, multu simul iterum revertitur, fertur que deorsum. Hæc Aristoteles. Pro cuius loci explicatione illud sciendum est, Cordis meatus ita a natura paratos esse, ut ex vena cava intromisio fiat in cordis ventriculum dextrum, unde patet exitus in pulmonem. Ex pulmone præterea alium ingressum esse in cordis ventriculum sinistram, ex quo tandem patet exitus in arteriam. Aortam, membranis quibus dam ad ostia vasorum appositis, ut impediant retrocessum sic enim perpetuus quidam motus est ex vena cava per cor et pulmones in arteriam Aortam, ut in quæstionibus peripateticis explicavimus. Cum autem in vigilia motus caloris nativi fiat extra scilicet ad sensoria, in somno autem intra, scilicet ad cor, putandum est in vigilia multum spiritus et sanguinis ferri

ad arterias, inde enim in nervos est iter. In somno autem eumdem calorem per venas reverti ad cor, non per arterias, ingressus enim naturalis per venam cavam datur in cor non per arteriam Indicio sunt pulsus, qui ex pergiscentibus fiunt magni, vehementes, celeres, et crebri cum quodam vibratione, in somno autem parvi, languidi, tardi et rari de cau, pul 9 et 10.—Nam in somno calor nativus minus vergit in arterias, in eosdem erumpit vehementius, cum expergiscuntur. Venæ autem contrario modo se habent, nam in somno fiunt tumidiores in vigilia exiliores ut patet intuenti eos quæ in manu sunt. Transit enim in somno color nativus ex arteriis in venas per osculorum communionem quam anastomosin vocant & inde ad cor ut aute sanguinis exundatio an superiora &c. retrocessus ad inferiora instar Euripi manifesta est in somno et vigilia, sic non obscurus est huru modo motus in qua cunque parte corporis vinculum adhibeatur aut alia ratione occludanter venæ Cum enim tollitur permeatio, intumescunt rivuli qua parte fluere solent. Forte recurrit eo tempore sanguis ad principium ne intercisus extinguatur."

"Truly, from this proposition, it is not to be wondered at that sometimes sleep alone is produced, by the seizure of the veins in the neck, sometimes even suffocation. For it is necessary from that seizure, that the power of the heart is not communicated to the brain, so the consciousness and voluntary motion of the whole body is taken away, but it is not necessary, for such an effect, to fill the lungs to suffocation. But that appears worthy of observation, for the reason that the veins swell up from a bandage on the other side of the seat of application, not this (towards heart), which those know from experience who bleed, for they apply the bandage this side of the position of section,

not on the other side, because the veins swell up on the other side of the bandage, not this side. But the opposite way ought to happen if the motion of the blood and spirit is made from the viscera into the whole body, for the canal being intercepted, progression is not given, therefore, the swelling of the veins ought to be made on this side of the bandage. Or, indeed, our doubt is solved of that which Aristotle writes of sleep, Cap. 3, where he says, Necessarily what is evaporated, impelled continually elsewhere, is then turned back and changed, like the Euripus; for the heat of every animal is intended by nature to be carried to the higher parts, much, at the same time, on the other hand, is turned back and carried downward. So, Aristotle. For the explanation of this passage we must know this. That the cavities of the heart are so prepared by nature that there is an opening made from the vena cava into the right ventricle of the heart, whence an exit into the lungs is open. Further, from the lungs there is another opening into the left ventricle of the heart, from which, finally, an exit is open into the arterial aorta, the valves of which are placed at the mouths of the vessels, in order to impede retrogression. For thus there is a perpetual motion from the vena cava, through the heart and lungs, to the arterial aorta, as we have explained in the peripatetic questions. But since, when we are awake, the motion of the native heat is outwards, that is, towards the sensorium, but in sleep inwards, that is, towards the heart, we must be led to think that while we are awake much spirit and blood are carried to the arteries, for thence is the way to the nerves. But in sleep the same heat reverts, by the veins, to the heart, not by the arteries, for the natural entrance to the heart is given by the vena cava, not by the artery. The evidence of this is the pulses, which, while we

are awake, are made great, vehement, rapid, swift, with each vibration, but in sleep small, languid, slow, infrequent (3 de can. pul. 9 and 10). For in sleep the native heat tends less towards the arteries, it bursts forth into the same most vehemently when they are awake. But the veins have a contrary habit, for in sleep they become more swollen, and when we are awake more empty, as is evident by observing those which are in the hand. For the native heat, in sleep, passes from the arteries to the veins by their common mouths, which they call anastomoses, and thence to the heart. But the pouring out of the blood to the higher parts and its retrocession to the inferior ones, like that of the Euripus, is manifest in sleep, and when we are awake, for this kind of motion is not obscure in whatever part of the body the bandage is applied, or by whatever other means the veins are closed up. For when the permeation is allowed, the rivulets swell up in the parts by which they are accustomed to flow. The blood recurs powerfully at that time to its source, lest, having been cut off, it be extinguished."

It will be observed that in this passage the word Euripus occurs twice. In the first instance, however, it is Aristotle that uses it, expressing by it in a metaphorical way, his view as to the ebb and flow of the heat of an animal; Euripus being a narrow sea between Bœotia and Eubœa, which, according to the ancients, ebbed and flowed several times a day. Hence, we find several writers using the word Euripus to express an oscillation of any kind. As we are not concerned at present with what Aristotle or Cæsalpinus thought of animal heat, it is not necessary to dwell further upon this part of the passage, simply mentioning that Cæsalpinus says nothing as regards the heat as evidenced by the pulse, etc., which is inconsistent with what is

known at the present day, the heat going to the heart by the veins, not by the arteries. In the second instance where the word Euripus occurs, Cæsalpinus uses it metaphorically, in the sense of an oscillation; but in this case, as applied to the blood. It is distinctly stated that the blood is poured out towards the superior parts, and retrogrades to the inferior ones, both asleep and awake. The ebb and flow is from the heart to the head and back again, by the arteries to the head, by the veins to the heart, there being a perpetual motion from the vena cava to the heart, through the lungs back to the heart, and so to the arteries; thence the way to the nerves, the nerves being nourished by arterial blood, like all the other structures. Not a word is said of there being an ebb and flow, a Euripus-like motion, in the veins; on the contrary, it is distinctly said that the blood flows in the veins towards the heart, as can be proved by binding up a vein anywhere. It will be observed that Cæsalpinus says that the natural heat passes, only during sleep, from the arteries to the veins, by anastomoses. This statement, however, is a totally different one from saying that the arteries anastomose only with the veins during sleep. If there are anastomoses during sleep, there are anastomoses during the wakeful condition. More heat may be generated and transmitted through the economy at one time than another, but the absence of all heat would not affect the existence of the anastomoses. Cæsalpinus, so far from saying that the blood passes from the arteries to the veins only during sleep, says that the motion of the blood is perpetual, during both the sleeping and waking conditions. That Cæsalpinus understood that the blood circulated, and did not simply irrigate the system, seems to be proved by the fact of his saying that the blood circulates in one work, in another that the blood

is carried by the veins to the heart, and from the heart by the arteries, and that the arteries anastomose with the veins, and that the motion is perpetual from the vena cava to the heart and lungs to the aorta. It is not to be implied, however, that he understood the exact manner in which the blood passed from the arteries to the veins because he uses the word anastomoses. Galen and Servetus used the same word in this connection, as also afterwards Harvey, and yet there is no reason to suppose that these writers ever meant, by the word anastomosis, the capillaries, and yet, without a knowledge of these vessels, the systemic, no more than the pulmonary circulation, could be thoroughly understood.

It has been stated that Moreri (*Le Grand Dict. Hist., Paris,* 1732, Vol. II, p. 675) was the first to claim for Cæsalpinus the honor of the discovery of the circulation. This is incorrect, however, as Douglas, in his *Bibliographiæ Anatomicæ,* after paying a proper tribute to Harvey, observes that it is to be regretted that Cæsalpinus did not expose his views more fully. Nevertheless, that he (Cæsalpinus) who invented is as deserving of honor as he (Harvey) who perfected.

Bibliographiæ Anatomicæ, Jacobi Douglas, Londini, 1715, p. 140. "Et licet fælicissimus Angliæ adeo magnum anatomiæ lumen terrarum orbi offerenti medullitus congratuler, dolere tamen est, Cæsalpinum quæ perspicue satis nullisque verborum ambagibus intricata tradit non magis encoluisse & in Hypothesin generi humano profuturam perduxisse, nihilominus par decus manet & illum qui primum invenit & qui postremum perfecit, nescio enim an præstat invenisse an detasse."

It will be seen, from this brief résumé of the views of Servetus, Colombo and Cæsalpinus, that while the pulmonary circu-

lation (with the exception of the capillaries) was understood by Servetus and Colombo, they had but little or no idea of the general or systemic circulation; on the other hand, while the general circulation (with the exception of the capillaries) was correctly described by Cæsalpinus, he understood the pulmonary circulation only imperfectly. Throughout this lecture I use the terms pulmonary and systemic circulations in their conventional sense; but both these terms are incorrect and misleading, since the blood after leaving the left ventricle does not return at once to the right side of the heart, which would constitute a pulmonary circulation, but first passes through the system, and, having passed through the system, it does not directly return to the left ventricle, a systemic circulation, but passes through the heart and lungs first. There is, therefore, but one circulation. But this is only true in a certain sense, as the blood, after leaving the heart, may go to the head or the extremities, etc., and then return to the heart. As a matter of fact there are, therefore, innumerable circulations. It cannot be said, therefore, that any one, up to the end of the 16th century, understood the entire circulation of the blood, using the word circulation in the sense that we do at the present day. Isolated portions of the circulation only had been described. It remained now for some one to show the connection between the facts already established, to add important new ones, to offer a view based upon observation and experiment that would explain all the facts. In a word, to demonstrate that the blood actually circulates.

It is claimed by some writers that this honor should be accorded to Carlo Rumi, of Bologna, it having been asserted that Rumi discovered both the pulmonary and systemic circulations. Even if Rumi had described both the circulations

correctly, that would not have entitled him to have been called their discoverer, since the pulmonary circulation had been previously describe by Servetus and Colombo, and the systemic circulation by Cæsalpinus. Rumi does not appear to me, however, to have thoroughly understood either the systemic or pulmonary circulations, since he states the veins carry the nourishment, as well as the arteries, to the viscera, and that the pulmonary arteries nourish the lungs. There can be no possible misunderstanding of Rumi's views as to the systemic circulation, as in his Anatomia del Cavallo, in Venetia, 1599 (Lib. I, p. 65), he says, "la vena che porta nutrimento allochio" (the vein that carries nutriment to the eye), and gives a figure (Tav. II, Fig. vii) illustrating this view. At p. 94, in speaking of the arteries and veins, we find, "che paiono esser fatte solamente per portar nodrimento a parte cosi nobile, come la spinal medolla," that appear to be made solely to carry nutriment to parts as noble as the spinal medulla; and at p. 100, they give nutriment, life and motion to all these parts,—a branch of the vein and artery "Danno nutrimento, vita, et moto a tutte queste parti, un ramo della vena et arteria." That Rumi had but an imperfect idea of the pulmonary circulation is evident from the manner in which he describes it, p. 108:—

"L'officio di questi ventricoli, e del diritto disponere il sangue, che di quello si possano generare li spiriti della vita, et nodrire i polomoni; del sinistro e ricever questo sangue gia disposto, et convertirne una parte ne gli spiriti, che danno la vita et mandare il restante insieme con quelli spiriti, per l'arterie, a tutte le parti del corpo Nell uno et nellaltro ventriculo, sono due bocche o pertugi per quelli del diritto entra il sangue della vena grande, o cava et esce per la vena arteriale et per quelli del ventricolo

manco entra il sangue accompagnato dall aere preparato nei i polmoni per l'arteria venale il quale fatto tutto spirituoso, e perfettissimo vel ventricolo sinistro esce (guidato dall arteria grande) per tutte le parti del corpo eccetto che per li polmoni per farle partecipe di qualche calore, che li da la vita."

"The office of these ventricles is, for the right one, to prepare the blood, that the spirits of life can be generated from it and the lungs nourished; of the left, to receive this blood already prepared, and to convert a part into spirits, which give life, and to send the rest, together with the spirits, by means of the arteries, to all parts of the body. In both the ventricles are two mouths or chinks; by that of the right the blood of the great vein, or cava, enters, and goes out by the arterial vein; by that of the left ventricle, the blood enters, accompanied by the air prepared in the lungs from the venous artery; this being entirely spiritualized and perfected in the left ventricle, goes out (guided by the great arteria) through all parts of the body, except that for the lungs, to impart it that heat which gives life."

During the middle of the 16th century the fame of the medical schools of Italy had spread far and wide. Students from all parts of Europe crowded to listen to the eloquent lectures of Vesalius, Eustachius and Fallopius, to attend the anatomical demonstrations given in the amphitheatres at Padua, Pisa and Bologna. At the end of the 16th century, with other foreigners, William Harvey came to Padua and studied with the celebrated Fabricius, of Aquapendente, the first anatomist to thoroughly describe, in his "De venarum ostiolis, Patav, 1603," the valves in the veins.[1] Fabricius is often said

[1] *Hieronymi Fabrici ab Aquapendente Opera Omnia Lipsiæ*, 1687, *De*

to have been the first to have discovered these valves; indeed, he says so himself; but the presence of valves in the veins had been previously noticed by several anatomists; among others, by Cannanus,[1] Sylvius,[2] Eustachius[3] and Piccolhominus.[4] At this

Venarum Ostiolis, p. 150. "Sed neque aliquis prius hæc viderit quam Anno Domini septuagesimo quarto supra millesimum et quingentessimum quo a me summa lætitia inter dissecandum observata fuere."

[1]Amati Lusítani Medici Physici Præstantio Curationum Medicinalium, Lugduni, 1567. In this work, p. 271, Lusitanus mentions having demonstrated the valves in the azygos vein in man and in animals, at Ferrara, in 1547; and refers to Cannanus as having previously noticed them also: "nam anno 1547, Ferrariæ, duodecim corpora humana brutorun dissecare fecimus in omnibus ita evenisse magna doctorum hominum spectante concione videmus ut itidem quoque adnotabat Joanus Baptista Cannanus admirandus anatomicus."

[2]In Hippocrates et Galeni Physiologiæ partem anatomicam Isagoge a Jacobo Sylvio-Parisiis, 1555. In Cap. IIII, p. 17, of this work, Sylvius refers to the valves in the azygos, brachial, crural, etc., veins, considering that they act like those closing the mouths of the cardiac vessels: "Membranæ quoque epiphysis est in ore venæ azygi, vasorum que aliorum magnorum sepe ut jugularium, brachialium, cruralium trunco cavæ ex hepate profiliensis usus euisdem cum membranis ora vasorum cordis claudentibus."

[3]Bartholmæi Eustachii Opuscula Anatomica Venetiis, 1584. Eustachius, in his work, De Vena Sine Pari, p. 289, after describing the valve named after him, refers to the valves in the coronary veins: "pariter atque illa quam orificio venæ coronariæ præfici dixi, quasi cornutæ lunæ speciem refert, aliquando adeo parva et augusta est, ut nisi diligenter animum quis advertat, quasi nulla sit prætereatur."

[4]Anatomicæ Prælectiones Archangel Piccolhomini Romæ, 1586. According to Piccolhominus, the excitement of the discovery of the valves in the veins threw him almost in ecstacy. At p. 412 he observes: "Unum solum eis addere volo magni momenti ab omnibus prætermissum quod mihi summam admirationem quum illud comperi ita excitant ut fere in exstasium ageret, quod est in mediis venis reconditas esse innumerabiles pene valvas quemad

moment, however, that which interests us particularly in reference to these valves is, that Fabricius demonstrated them to Harvey, and that the latter made such good use of that knowledge that the names of pupil and master have ever since been associated; for undoubtedly it was reflection upon what might be the use of the valves, as well as other anatomical considerations, that first led Harvey to investigate the manner in which the blood flows through the system. Harvey studied about five

modom in orificiis vasorum cordis. Hæ venarum valvæ maximæ conspicuæ sunt in divisione ramorum venæ cavæ, quarum aliæ superne deorsum aliæ inferne sursum spectant. Ex gr ubi vena cava diducitur in jugularem externam et internam, ibi collocatæ jacent valvæ superne deorsum spectantes quem in usum et finem.—Hunc igitur in finem in superioribus venis fabræfactæ sunt valvæ superne deorsum spectantes, ne in decubitu, confertim sanguis in cerebrum impetat, mille cerebri affectus præternaturam procreaturus. Similiter in inferioribus venis ex gr ubi vena cava bipartito scinditur in tibias progressura, sunt collocatæ valvæ inferne sursum spectantes. Ex quem in usum. Ne sanguis quum sit gravis et fluidus totus repente procumbat in pedes, inferiores que partes."

By most writers the French anatomist, Etienne, is considered to have described the valves in the veins even before Cannanus or Sylvius.—De dissectione partium corporis humani libri tres a Carolo Stephano. Parisiis, 1545. Lib. II, Hepar, Cap. IX, p. 182—"Porro autem ne sanguis qui elaboratur in hepate interdum regurgitet facti sunt a natura quidam veluti exortus &c. apophyses membranarum quæ huius modi periculo obsint quemadmodum in corde valvulæ ad spiritus conservationem." By apophyses Etienne, however, probably refers not to valves, since there are none, at least in the hepatic veins of man, but to the semilunar folds seen at the lower border of the orifices of the hepatic veins, at their entrance into the vena cava.

By a few writers it has been said that the celebrated Italian, Father Paul Sarpi, not only described the valves in the veins, but also discovered the circulation of the blood; and that Fabricius was indebted to Sarpi for his knowledge of the valves. So far as I have been able to learn, this view appears to rest on no better authority than such was the opinion of the Vene-

years at Padua (1598–1602). Naturally, during that time he became thoroughly acquainted, not only with the views of his teachers, Fabricius, Rudio, etc., but also with those of Colombo, and probably of Cæsalpinus and others who had taught and written concerning the manner in which the blood was supposed to flow. Perfectly familiar with the anatomical views and methods of the school of Padua, dissatisfied with the prevailing imperfect physio-

tian, Father Fulgentius, and of Peiresc, Senator of Aix. In a letter, written from Pavia, October 30th, 1642, to Walaeus, Professor in Leyden, by Bartholinus, the latter states that, apropos of the Harveian circulation, Vesling had told him a secret, to be revealed to no one, namely, that it was Sarpi who had discovered the circulation and demonstrated the valves to Fabricius, and that Sarpi's views were contained in his manuscript preserved at Venice, by his disciple, Fulgentius.—Thomas Bartholinus Epistolæ Hafniæ, 1663, cent I, epist XXVI—"De circulatione Harveyana secretum mihi aperuit Veslingius nulli revelandum; esse nempe inventum Patris Pauli Veneti (a quo de ostiolis venarum sua habuit Aquapendente) ut ex ipsius autographo vidit, quod Venetiis servat P. Fulgentius, illius discipulus et successor."

In his life of Peiresc, Gassendi observes, in speaking to Peiresc of the remarkable work of Harvey, on the circulation, recently published, that he had mentioned to Peiresc that Harvey lay great stress upon the valves in the veins as a proof of the circulation, and that Peiresc had heard something about these valves from Fabricius, and remembered that Sarpi had discovered them.

Viri Illustris Nicolai Claudii Pabricii de Peiresc Senatoris Aquis extiensis Vita. Hagæ Comitis, 1651, per Petrum Gassendum, p. 323.

"Cum simul monuissem Gulielmum Harvaeum Medicum Anglum, edidisse præclarum librum de successione sanguinis ex venis in arterias, & ex arterias rursus in venas, per imperceptas; anastomoseis inter cætera vero argumenta confirmasse illam ex venarum valvulis de quibus ipse inaudierat aliquid ab Aquapendente, &c quarum inventorem primum Sarpium Servitam meminerat; ideo statim voluit & librum habere, & eas valvulas explorare, & alia internocere; veluti mæandros mediastini cordis, quos Harvaeus est insiciatus, et de quibus ipse feceram securum.

logical theories of the circulation, on his return to England, Harvey began anew the study of the flow of the blood. The results of his reflection upon the knowledge gained in Italy, of his studies on his return, by numerous vivisections, of extended comparisons of the structure of the heart and blood vessels in the animal kingdom, of pathological observations upon man and beast, were embodied in his classical treatise, "An Anatomical Exercise on the Motion of the Heart and Blood in Animals."[1] This deservedly famous work will always serve as a model for physiological investigation. Thus Harvey shows the necessity of making vivisections[2] in the study of the circulation, and too much stress cannot be laid upon this statement, as it is often said that the circulation of the blood was discovered without recourse to experiments upon living animals. The importance of comparative anatomy as an aid to the study of physiology is well shown by the use that Harvey made of his knowledge of the structure and functions of the heart in the lower animals, in his researches upon the circulation. Indeed, Harvey says,[3] had anatomists only been as familiar with the dissection of the lower animals as they are with that of the human body, matters that have been a source of doubt would be free from all difficulty. Unfortunately, comparative anatomy is too much neglected by physiologists at the present day. That the value of pathological anatomy in throwing light upon the normal functions of the body was thoroughly appreciated by Harvey is evident from the cases

[1] Exercitatio anatomica de motu cordis et sanguinis in animalibus. Francofurti MDCXXVIII.

[2] Op. cit., Cap. II, p. 21, Ex vivorum dissectione, etc. Cap. IV, p. 25. Motus cordis, etc., ex vivorum dissectione.

[3] Cap. VI, p. 32. Quibus viis sanguis e vena cava in arterias.

he refers to[1] in connection with his study of the circulation. Harvey, therefore, did not confine himself to any one method of investigation, but availed himself of vivisections, comparative anatomy and pathology in his researches. It may be seen, by referring to the writings of the great predecessors of Harvey, that with the exception of Cæsalpinus, it was always assumed that the venous blood flowed from the viscera to the periphery. Undoubtedly Harvey demonstrated far more thoroughly, by experiment and argument, than Cæsalpinus, the true course of the venous blood, and this he proved in many different ways. Thus, in his thirteenth chapter,[2] after referring to the discovery of the valves of the veins by Fabricius, and the different uses that had been assigned to them, Harvey proceeds to show that the valves are disposed in such a way that they only permit the blood to pass through them in one direction, and that is towards the heart,[3] demonstrating this by calling attention, as Cæsalpinus had done before him, to the condition of the veins when compressed as if for bleeding. At intervals in the course of the veins, under such circumstances, large knots are visible, which are due to

[1] Cap. III, p. 34. Arteriarum motus qualis ex vivorum dissectione.

[2] Cap. XIII, p. 54. Tertium suppositum confirmatur, etc.

[3] It must not be forgotten, as may be seen from the quotation given at p. 41, Note 4, that Piccolhominus had already described the valves in the jugular vein as looking from above downward, and those in the veins in the extremities as looking from below upward, and drew the conclusion, from such disposition, that these valves prevented regurgitation to the head and extremities respectively. It is to be regretted that Harvey, in his description of the valves and the flow of blood through the veins, should never have mentioned either Piccolhominus or Cæsalpinus, as it is probable that he was acquainted with the writings of these anatomists, both teaching at Rome about the same time.

the distended valves which thus show themselves externally. By pressing upon these veins above or below, or between the valves, Harvey showed that the venous blood always passed in the same direction, that is, toward the heart, and concluded that the functions of the valves were like those of the semilunar valves of the pulmonary artery and aorta, to prevent all reflux.[1] Excellent figures are given in this chapter to illustrate the experiments by which the functions of the valves were demonstrated. Further, that the blood flowed towards the heart in the veins and from the heart in the arteries, was beautifully demonstrated by an experiment upon a living snake, so clearly described by Harvey in Chapter x. After noticing the pulsating heart in the snake as it appeared after the animal had been opened, Harvey calls attention to the fact that if the vena cava be compressed it gradually empties itself between the point of compression and the heart; whereas, if the aorta be compressed, it becomes distended between the heart and the point of compression, showing conclusively that the blood in the vena cava flows towards the heart, while that in the aorta flows from the heart. In his second answer to Riolan, Harvey[2] gives further proof of the circulation in noticing that in a divided artery the blood flows from the end of

[1] The importance of the valves in the veins, either functionally or as leading to the discovery of the circulation, must not be exaggerated, since in many veins there are no valves. Thus in man, at least, however it may be in other mammals, valves are not found in the venæ cavæ, the innominate, pulmonary, portal, hepatic, renal, uterine, ovarian, iliac, spinal, veins. Further, there are few valves in the veins of birds, reptiles or fishes, and none in the veins of the Invertebrata, and yet the blood circulates in all these animals. It is evident, therefore, that the valves in the veins are not indispensable in the maintenance of the circulation.

[2] Opera Omnia Edita, 1766, p. 120. Exercitatio altera ad J. Riolanum.

the vessel that is still in connection with the heart, whereas in the divided vein the blood flows from that part of the vessel separated from the heart. One of the most remarkable proofs of the circulation of the blood advanced by Harvey[1] is, that more blood passes through the heart in a given time than can be accounted for by the ingesta or by the quantity of the blood in the vessels; hence the blood must pass and repass through the heart, and in estimating the amount of blood flowing from the left ventricle into the aorta during a short period of time even, we necessarily count the same blood over and over again. Harvey was not only the first to correctly describe the entire circulation, but in the great work[2] we have so often referred to is found the first accurate account of the movements of the heart, the successive dilations and contractions of the auricles and ventricles, the contraction, hardening and elevation of the heart against the chest, etc. An excellent description, as may be supposed, is also given of the pulmonary circulation, etc. Further, though from the days of Aristotle it was known that there was some connection between the beating of the heart and the pulse, Harvey[3] showed clearly that the dilatation of the artery, or the pulse, was the effect of the contraction of the ventricle. Harvey was not the first, however, to show this, since in an ancient work, "Synopsis peri Sphugmon," by an unknown author, the pulse in this respect was correctly described. When this work was first discovered, according to D'Aremberg, it was, without any reason, attributed to Rufus, of Ephesus. The description I refer to is to be found at p. 20:—

[1] Cap. IX, p. 42.

[2] Cap. II, III, IV, V, VI.

[3] Cap. III, p. 24, Arteriarum motus qualis ex vivorum dissectione.

Συνοψις περι σφυγμων, Traite sur le Pouls attribué a Rufus d'Ephese, par le Dr. Ch. Daremberg, Paris, 1846, p. 20.—*Πῶς γίνεται σφυγμός; Γίνεται δε σφυγμὸς οὕτως. Ἡ καρδία ὅταν ἐπισπάσεται ἐκ τοῦ πνεύμονος τὸ πνεῦμα πρώτη αὐτὸ δεχεται εἰς τὴν ἀριστερὰν αὐτῆς κοιλίαν, εἶτα ἐπισυμπεσοῦσα ἐφεξῆς αὐταῖς ταις ἀρτηρίαις ἐπιχορηγεῖ. Συμβαίνει οὖν, ἐπὶ μὲν τῆς συμπτώσεως πληρουμένων τῶν ἐν τῷ σώματι ἀρτηριῶν τὸν σφυγμὸν ἀποτέλεῖσθαι, κενουμένων δὲ τὴν συστολήν αἱ μὲν οὖν ἀρτηρίαι, καθὼς εἶπον, τὸν σφυγμὸν ἀποτελοῦσι πληρούμεναι καὶ δεχομέναι τὸ πνεῦμα, ἡ δὲ καρδία κενουμένη καθὼς ἐξῆς υποδείξομεν.*

"How is the pulse generated? The pulse is produced as follows: The heart, after having drawn in the air from the lung, first receives it in its left cavity, then falling back upon itself immediately distributes it to the arteries; it follows, then, that, during the collapse of the heart, the arteries of the body being filled, their pulse is produced, and when empty, their systole. As I say, the pulse is produced in the arteries when full and receiving the air, and in the heart when empty, as we establish below."

In his view of the contraction of the ventricle being the cause of the dilation of the artery, Harvey was anticipated also in modern times by Cæsalpinus, who observes in his Quæstionum Peripateticarum, 1593, Lib. Quint, Quæst. IIII, p. 122, that "it happens that when the heart is contracting, the arteries are dilated, and it dilating, are contracted."

"Cum enim vasorum in cor definentium quædam intromittant contentam in ipsis substantiam, ut vena cava in dextro ventriculo & Arteria venalis in sinistro quædam educant, ut arteria aorta in sinistro ventriculo et vena arterialis pulmonem nutriens in dextro, omnibus autem membranulæ sint appositæ ei officio delegatæ ut oscula intromittentia non educant & educentia non intromittant.

continget corde contrapente se arterias dilatari & dilatante constringi, non simul ut apparet."

For, on account of the vessels ending in the heart, some pour their contents into its substance, as the vena cava into the right ventricle and venous artery (pulmonary vein) into the left; some draw out, as the arterial aorta, from the left ventricle, and the arterial vein (pulmonary artery), nourishing[1] the lungs from the right, but in all are valves placed and adapted to that use that their mouths, allowing to enter, do not lead out again, and those leading out to do not allow to enter again; it so happens that, the heart contracting, the arteries are dilated, and dilating, contracted, not at once, as appears.

I might dwell further upon the numerous observations, demonstrations, arguments based upon vivisections, comparative anatomy, pathology, etc., to be found in Harvey's work. The above brief descriptions will suffice, however, in giving an idea of the general methods of investigation and the results accomplished. The proofs advanced by Harvey were so numerous and convincing as to render the conclusion that the blood circulates inevitable. It was the only theory that would explain all the facts, the only view that enabled one to sift the truth from the error in the theories that had been advanced before Harvey's time. There is no doubt that Harvey was the first to teach that the blood flows from the right side of the heart through the lungs back to the left side of the heart, thence into the aorta and arteries throughout the body, from the arteries into the veins, returning by the veins to the heart

[1] It will be observed, from Cæsalpinus referring to the pulmonary artery being nutritive, that, as already mentioned, he did not understand the pulmonary circulation.

again—in a word, that he was the first to thoroughly describe the entire circulation; but it must be admitted that he did not demonstrate it, for there is no reason to suppose that Harvey ever understood exactly, still less demonstrated, the manner in which the blood flows from the arteries into the veins, since the capillaries were not discovered till after his death.

With the discovery of the capillaries by Malpighi and Leeuwenhoek the entire circulation was for the first time demonstrated. That Harvey did not understand the manner in which the blood flowed from the arteries into the veins is evident from his own description. His words[1] are: Signum est, etc., sanguinem ab arteriis in venas et non contra permeare et aut anastomosis vasorum esse aut porositates carnis et partium solidarum pervias sanguini esse"—that it "is obvious that the blood passes from the arteries into the veins, etc., and not the contrary; and that there are either anastomoses of the vessels or porosities of the flesh and solid parts that are pervious to the blood." Had Harvey ever seen the capillaries, or even had an idea of their structure, you may be assured that his description would have been a graphic one. There would have been no obscurity in reference to such an all important matter. That Harvey means by the word porositates, porosities or holes, and not capillaries, is evident from the way in which he uses this word in the introduction to the Exercitatio, where, in speaking of the theory of the ancients as regards the transmission of the blood through the septum of the heart, he says they hold "that there are numerous porositates in the septum of the heart, adapted for the transmission of the blood; but, by Hercules, there are no porositates, neither can they be demonstrated"—"in septo cordis

[1] Cap. xi, p. 48, Secundum suppositum Confirmatur.

porositates pleures esse producendo sanguini accommodatas. Sed me hercule porositates nullæ sunt necque demonstrari possunt."—Prooemium, p. 18. If by porositates Harvey means capillaries, he would deny, then, that there are any capillaries in the septum of the heart. Harvey appears to me to use the word porositates just in the same sense (that of holes or porosities) as used, as we have seen, by De Carpi, Vesalius, etc., in their description of the septum of the heart. As regards the word anastomoses, Servetus and Cæsalpinus speak of the arteries passing into the veins by anastomoses, and there is no more reason for supposing that Harvey understood by this word capillaries, than that they did. As an expression of the general opinion at that time, about this matter, I will mention, incidentally, that Wotton[1] observes: "There was one thing still wanting to complete this theory, and that was the knowledge how the veins received that blood which the arteries discharged. This put them upon imagining that the blood oozes out of the arteries and is absorbed by the veins, whose small orifices receive it (which opinion has been generally received by most anatomists since Dr. Harvey's time). (But Monsieur Leeuwenhoek has lately found in several sorts of fishes, which were more manageable by his glasses, that arteries and veins are really continued syphons wound about each other towards their extremities, in numberless mazes, over all the body)."

In a very learned and critical article that appeared in the *American Journal of the Medical Sciences*, for April, 1878, Dr. Wm. S. Forbes endeavored to show that the word porositates should be translated thin-walled vessels or capillaries. The point to be determined is not how porositates ought to be trans-

[1] Reflections, etc., p. 235.

lated, but what idea Harvey meant to convey by the use of this word. Even admitting, which I do not, that by porositates Harvey meant capillaries, there is no reason to believe that Harvey ever had seen these "thin-walled vessels," and without demonstrating the capillaries the entire circulation cannot be proved.

For the discovery of the capillaries, in 1661, science is indebted to Malpighi.[1] In examining the lung of a living frog, by means of the microscope, this distinguished physiologist actually saw the blood passing from the arteries into the veins by means of extremely delicate tubes, at once the terminal branches of the arteries and the beginnings of the veins. These minute intermediate connecting tubes, the capillaries, were also seen by Malpighi in the mesentery of the living frog as well as in the lung. Some time after Malpighi's discovery, the capillary circulation was observed by Leeuwenhoek[2] (1688), the Dutch naturalist, with a microscope, in the lung of a bat, in the tadpole's tail, and in the fin of different kinds of fish. From that time forward, the magnificent spectacle of the capillary circulation became with microscopists a favorite subject for popular demonstrations. Between 1628, the epoch of the appearance of the "De motu cordis" of Harvey, and 1661, the year of the discovery of the capillaries by Malpighi, our knowledge of the circulation was extended by the discovery of the lacteals, etc. Obviously, without a knowledge of the lymphatic system, that of the circulation of the blood would be far from complete. In this connection, however, it will be only necessary to allude to

[1] Marcelli Malpighi, Opera Omnia, Lug. Bat., 1687. Tomus secundus De Pulmonibus Epistola II, p. 328.

[2] Arcan. Nat. Lugd. Bat., 1722, pp. 158, 163.

the names of Eustachius, Asselli, Pecquet, Rudbeck, Bartholinus, whose contributions to the discovery of the lymphatic system I have already described in my lectures upon absorption. As regards the history of the discovery of the fœtal circulation, that will be considered with the study of development. During the 17th century our knowledge of the exact manner in which the blood flows to all parts of the economy was greatly extended by the study of the vascular system, by means of injections. It is true this method of investigation had been occasionally attempted before this period, but with little success. It was not until Ruysch[1] had perfected the methods of Swammerdam and Horne, and had demonstrated, by his very perfect injections, the manner in which the blood vessels are distributed through the tissues, that this method of study became universal with anatomists. It can be readily understood that when arteries, capillaries and veins are filled with a colored injection, how much easier the course of these vessels can be made out, with either scalpel or microscope, than if these blood vessels were simply studied in the state in which they are usually found in the body after death. Indeed, one of the most striking demonstrations of the continuity of the vascular system consists in injecting a fluid into an artery until the fluid escapes by an opening made in the vein. Further, during the 17th century, so fertile in discovery, the first attempts were also made in the study of the circulation of the invertebrata, Willis,[2] for example, describing the results of his researches upon the circulation of the oyster, lobster, etc.

[1] For an account of Ruysch, see eloge, by Fontenelle, in Hist. de l'Acad. Sciences, 1731, and Hyrtl, Lehrbuch der Anatomié, 1881, p. 61.

[2] Willis' Works, translated by S. Pordage, London, 1684: Of the Soul of Brutes, Chap. 3d, pp. 10, 11, Tables II, III.

It is, however, only during the present century that physiologists have understood the circulation of the blood as it takes place in the mollusca, articulata, etc., the vascular system of animals, like insects, crabs, spiders, oysters, snails, etc., differing very much from that of man or the mammalia; Milne Edwards, more especially, having shown, among other peculiarities, for example, that the interorganic spaces or lacunæ play the part of blood vessels in the invertebrata, as is the case in certain parts of the body of vertebrates also. Within the past twenty-five years great advances have been made in extending our knowledge of the circulation in other directions. Thus, by the introduction of the graphic method of study, we have seen, by means of kymographions, sphygmographs, cardiographs, etc., that we can determine blood-pressure, the rapidity with which the blood flows in the system, etc., while the discoveries of Bernard, Brown-Séquard, Ludwig, etc., have shown us how local variations in the general circulation are due to the influence of the vaso-motor nerves.

If our account has been a correct one, the history of the discovery of the circulation, recapitulated, divides itself naturally into a series of epoch-making periods—

1. The structure and functions of the valves of the Heart. Erasistratus, B. C. 304.

2. The Arteries carry blood during life, not air. Galen, A.D. 165.

3. The Pulmonary circulation. Servetus, 1553.

4. The Systemic circulation. Cæsalpinus, 1593.

5. The Pulmonic and Systemic circulations. Harvey, 1628.

6. The Capillaries. Malpighi, 1661.

The history of the discovery of the circulation, like all other great movements, social, political and scientific, illustrates the

profound truth that intellectual development is as surely a growth regulated by law as the life of a plant or animal. That no intellect, however magnificent, rises so above the conditions of its environment as to make it doubtful, for a moment, but that the discovery would have been made sooner or later, even had the name with which it is usually associated never existed. Every mind is the product of its age. All the circumstances prove that intellectual Europe at the end of the 16th century was ready to accept the circulation of the blood. Had the discovery been made some centuries sooner it would have fallen still-born. All Italy, at that period, was alive with speculation, hypothesis, theory, as to the manner in which the blood flowed through the body, and above all, Padua. Let any one compare the works of the great Italian anatomists and physiologists of the 16th century, in their Latin or Italian dress, with the admirable work of Harvey on the Circulation, in the original, and not in an English translation, and he will be impressed with the fact that the same mode of thought and expression pervades both. In his methods of investigation, observation, arguments, Harvey is essentially Italian. By birth an Englishman, in thought Italian, Harvey lived and died a student of Padua.

The discovery of the circulation of the blood, as we learn from this necessarily brief account, belongs, therefore, to no one age, country or person. Its history, extending as it does over a period of over 2000 years, would naturally suggest that the subject would have attracted the attention of the great medical minds of all time; and such we have seen to have been the case. Far from the grandest generalization in the whole range of biology being discovered in its entirety by one mind, we have

seen how, little by little, it was gradually established by many observers; that long intervals would elapse without any progress being made, when suddenly some ancient error would be dissipated and fade away in the light of advancing science. Such a history ought to encourage every student, for however trivial and unimportant his experiments or observations may appear at the time, every new fact once well established will sooner or later assume its appropriate place as a part of some future generalization; the chain of facts leading to a great discovery being united together like living things, each linked with those that have passed away with those still to come. Discoveries great in themselves have often borne no fruit at the time, falling on barren soil, the human mind not being sufficiently developed to appreciate them. With the progress of knowledge, however, the significance of discoveries made often ages ago and long forgotten, become, in time, apparent to all. Truth, like the rays of the rising sun, is perceived first by those whose minds soar above the intellectual horizon of their day, but sooner or later its genial influence is felt by their humble followers, by all alike, all in good time.