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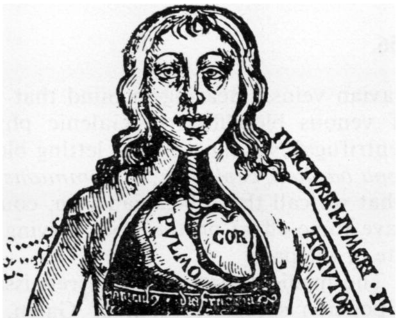

The thorax in history 5 Discovery of the pulmonary transit

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The discovery that blood passes from the heart to the lungs and from the lungs back again to the heart was the first major development in physiology since the early days of the Alexandrian school more than a thousand years before. It followed shortly after the rediscovery of the ancient writings, particularly those of Galen and Aristotle. The scholarly evaluation of these texts showed that on certain fundamental issues, in our case the structure and function of the heart and lungs, Aristotle's opinion could not be reconciled with that of Galen. The same texts provided a model of scientific procedure including a considered evaluation of scientific "fact" derived from historical sources. Finally, medieval human dissection provided the means whereby this scientific method could be put into practice and used to discover which, if any, of the ancient writers had been right in their descriptions of anatomy and physiology. Broadly, the natural philosophers followed Aristotle, and the medical men accepted Galen; everyone tried to follow Hippocrates, and the occasional zealot like Vesalius attempted to restore anatomy to its pristine Alexandrian glory, whence, he claimed, it had been corrupted by Galen's dissections of apes.

Where to let blood?

The comparatively rapid arrival of renaissance medical humanism at universities like Paris (where Vesalius spent some three years) sharpened the distinctions mentioned above and added another: that between traditionalists and moderns. "Traditionalist" now meant someone who admitted any value to the medieval and in particular the Arabic medical texts. Barengario da Carpi was such a man, who accepted, read, carefully considered, and pronounced judgement on almost every anatomical text that was available, whether Arabic, Greek, or Latin in origin. The medical humanists of the sixteenth century, a generation younger than da Carpi, preferred to forget about the Arabic texts in the belief that the Arabs had merely corrupted the true spirit of Greek medicine. Moreover, the Arabic texts in Latin guise contained ugly, barbaric words that did not decline properly and which obscured the meaning of the purer Greek.

The dispute about where to let blood was not merely an academic one, for it had immediate practical significance. The humanists found that the Greek texts of Hippocrates and Galen instructed the physician to let blood from a vein on the same side of the body as the diseased part, while the traditionalists believed the vein should be on the opposite side. Everyone agreed in general that blood was one of the four cardinal humours, and that disease was *dyscrasia*, or unequal mixture of humours; but when the disease was *localised* in the body it was obviously of great importance to know from where the physician was subtracting blood. The difference between "revulsive" (distant from the disorder) and "derivative" (close) bleeding was exactly this—that is, the traditionalists and the humanists had to employ exactly opposite techniques to achieve the same end. The dispute waged furiously in the earlier middle years of the sixteenth century, and although described by some historians[1] as futile, it was an essential component of medical thinking of the time and in fact prompted medical progress. The story was rehearsed in antiquity, in Galen's commentary on the Hippocratic *Regimen in Acute Diseases*,[2] where the Hippocratic author is discussing letting blood from the arm for pains of the thorax. Galen had much more anatomical knowledge than the Hippocratic writer, and Galen felt it his duty to put the advice of the revered "Hippocrates" on a sound rational basis by explaining the underlying anatomy. This meant giving a description of the azygos vein, literally the single, or asymmetrical vein, and the Galenic *rationale* behind the Hippocratic treatment was that the azygos, serving the lower eight ribs, joins the vena cava close to where the vena cava itself joins the heart, and not far from the junction of the vena cava with the subclavian veins.[3] Bearing in mind that the direction of venous bloodflow in Galenic physiology was centrifugal, we can see that letting blood from the *vena basilica, cephalica*, or *communis*, branches of what we call the subclavian vein, could be said to have some effect on the veins serving the ribs, the site of the pain.

The medical writers of the renaissance were in a position similar to that of Galen, inheriting a time-honoured therapeutic device from a respected teacher of antiquity, and anxious to put it on a "rational"—that is, modern—basis. Both Massa and Vesalius were aware of Galen's commentary on the Hippocratic text. It had been clear to anatomists like Barengario da Carpi that observation of the dissected body was the final arbiter between the conflicting accounts of the ancients, and the principle was much more readily applicable to the disputes between modern medical men. Would not all the difficulties of the modern physicians disappear, asked Niccolo Massa, if only they would devote themselves to the *anatomia sensata* of the veins? "To the anatomy of which, God willing, I intended to devote a separate book".[4] In fact Massa's *anatomia sensata* of the azygos was less than successful; disagreeing both with modern anatomy and with Galen he said that it arises from the vena cava at some distance from the heart (perhaps the result of his dissecting a dog)[5] and that it served the lower *ten* ribs. He actually described the vein as double, and so was either confused by the hemiazygos or by the paired azygos of the pig. Nevertheless, Massa's purpose in investigating the structure of the vein was to give a structural basis for the practice of phlebotomy, and he was led by close scrutiny of the (animal) body into disagreeing with Galen, an attitude that by now was essential to anatomical progress.

Massa's book was published in 1536, and practically his only predecessor as a critic of Galen was Barengario da Carpi. Three years later Vesalius was teaching anatomy at Padua. He too had strong ideas about the correct way to let blood, and the anatomical reasons behind it, and his reaction to the dispute between the traditionalists and the humanists was to take up his chalk or charcoal while teaching[6] and sketch out the course of the veins, including the azygos. (His physiology remained Galenic[7] and so the azygos was important in bloodletting). These sketches proved to be popular, and a set of them illustrating the systems of the body was published as the *Tabulae Sex*. The importance of the development of the graphic method in anatomical progress can hardly be overemphasised, and again we see that the spur to progress was the contemporary dispute over a therapeutic technique. Vesalius found himself at odds with Galen on various aspects of the question, and published his ideas in 1539 in the "Venesection letter"[8] (see fig 1). Vesalius's later criticism of Galen was central to the anatomical revolution of the sixteenth century, and it has been said that "The emancipation of Vesalius begins with the venesection letter."[9]

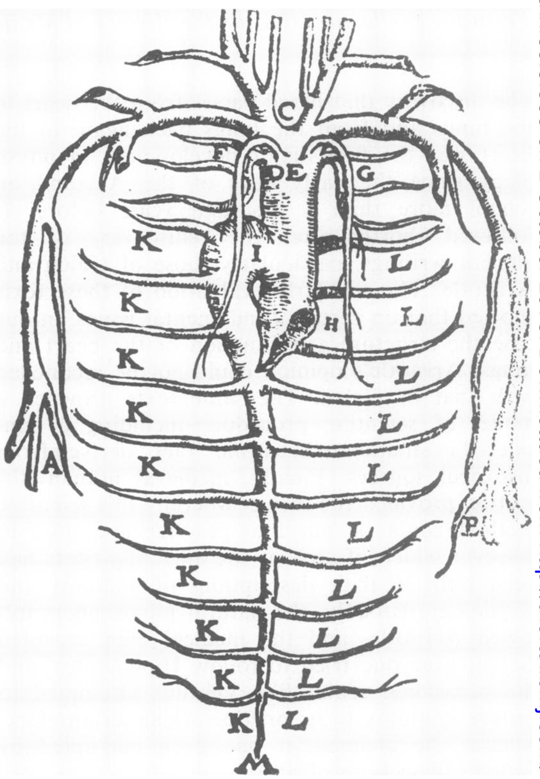

Fig 1 *Vesalius's drawing of the vena azygos, from the venesection letter.*

Nevertheless Vesalius was far from freeing himself from Galenic doctrine when he published the venesection letter and the *Tabulae*. His drawing of the aortic arch is almost certainly a reconstruction in pictorial form of Galen's words in his short guide to the anatomy of the blood vessels,[10] a book Vesalius was probably already preparing for the Junta edition of the collected works of Galen of 1541–2. Consequently Vesalius illustrates only two branches from the aorta, the left subclavian artery and a common trunk giving rise to the innominate and the right subclavian. Contemporary anatomists—da Carpi, Estienne, and Dryander—depended instead on Galen's *De Usu Partium* and so drew a single common trunk arising from the aorta and branching to form the other arteries. This description was probably derived from ungulates; Galen refers simply to "animals." In the short guide to the anatomy of the blood vessels he gives us simian or perhaps feline anatomy, and features from these three groups of animals turn up again in Vesalius's account of the heart and its veins.

The valves of the veins

We have seen, then, that because of its importance in bleeding for disorders of the thorax like "pleurisy," the azygos vein was closely inspected by anatomists who wished to supply a rational basis for an ancient technique. As a result of this interest the Italian anatomist Canano found valves in the azygos vein some time before 1546, when he related his discovery to Vesalius and other friends. Among these was Amatus Lusitanus, who made a dozen dissections in 1547 to confirm Canano's discovery. Amatus's purpose was to refute Vesalius's notion of the correct way of letting blood, in which the azygos vein played such an important part. This attack on Vesalius was reinforced by an apparently impressive anatomical demonstration involving the inflation of the vena azygos to illustrate the function of the valve.[11] His results, however, were entirely in accord with Galenic physiology, in which blood passes up from the vena cava into the azygos, and from there to the ribs. Of course, when *we* say "valve" we have in mind an efficient closing device that allows a flow in one direction only. Our models are the valves of the heart and the valves of machines, most likely those concerned with water. The standard notion of a valve in the sixteenth century was quite different: the valves of the heart, according to Galenic doctrine, allowed a small reflux to allow for the escape of metabolic waste products. The use of valves in machines was far less well known than it is today, and when a mechanical term was used for the valves in the body it was one that meant "door" or "gate," or, when the analogy was pressed hard, "sluice"—that is, a structure that holds up the bulk of the water but allows past a certain amount. So when new valves were found in the body—in the azygos vein by Canano, in the jugular by Sylvius, in the mesenteric veins by Colombo—it was naturally assumed that their function fitted into the pattern already established. Each case, had the valve been thought to act as a valve in our sense, would have been evidence for the circulation of blood, because each valve indicated that the flow of blood was to the heart and not from the heart. In fact the function of these valves was taken to be to slow down the centrifugal flow of venous blood. In a sense discussion about the valves in the veins was the most important step to the discovery of the circulation of the blood. During the sixteenth and early seventeenth centuries these structures were investigated by dissection as anatomical novelties, and their function debated. The terminology did not become fixed until the early seventeenth century, after a search through the anatomical literature and a review of similar structures elsewhere had suggested *valva* or *valvula* on the basis of an analogy with sluice and lock-gates. The word did not arrive in English until the second decade of the seventeenth century, in an English translation, which Harvey used, of a popular anatomical textbook. The notion of *valve* was critical, for to assume that the function of the structure was to *prevent*, not slow down, the centrifugal flow of venous blood was to destroy Galenic physiology.

Form, function, and discovery

But the total destruction of Galenic physiology was too big a step to take. The intermediate stage was the discovery of the pulmonary transit: this answered some recurring problems but could be accommodated to the rest of Galenic physiology. It gave expression to those who were the new champions of the observational method, and it was a discovery that could be used in the perpetual debate between the Aristotelians and the Galenists.

During this period we see a shift in scientific method that was of great importance to the development of modern medicine. Both Galen and Aristotle had emphasised the need for personal observation in biological research. The ages that followed these authors had concentrated instead on the results they had obtained, which during the middle ages had the status of inviolable texts. The renaissance restored the idea of testing inherited information by sense observation. But sense observation had its limits, and no one could rationally deny that there could be in the body structures that were too small to be seen but which might play an important part in its working. It was in this area that the relation between form and function, and between reason and observation, became very important and came to differ, in the renaissance, from the classical model.

This difference lay in the use of "reason." Aristotle had said that true knowledge of a part of the body was only achieved by understanding its function, or purpose, and that this could be gained by observing its structure and if possible its actions. This was a fairly straightforward discipline of sense observation, and Galen would have agreed with it, but in attempting to put it into practice in the particular case of explaining the form and function of the heart and lungs, Galen found himself in a difficulty. He had passionately denied Erasistratus's claim that there was only spirit in the arteries, and had resorted to experiment and observation to strengthen his case. Yet he accepted the fundamental difference the Greeks had assumed between the nutritive system (liver, right side of heart, vena cava) and the respiratory (lungs, left side of heart, arteries). To have had blood crossing from right to left across the lungs would have obscured this difference, and it would have meant Galen accepting the existence of anastomoses of the size and kind that Erasistratus had said allowed blood to enter the arteries from the veins when the arteries were cut (thus explaining bleeding from damaged arteries).

Unable to retreat from either position, Galen had no obvious way of explaining how blood, generated in the liver, could get into the left ventricle of the heart. He was obliged to use reason to postulate the existence of pores in the interventricular septum of the heart (at F in fig 2). They were invisibly small and their existence was incapable of being determined by sense observation. In other words anatomy was not the result of observation but was deduced from function. The function was determined by the position that

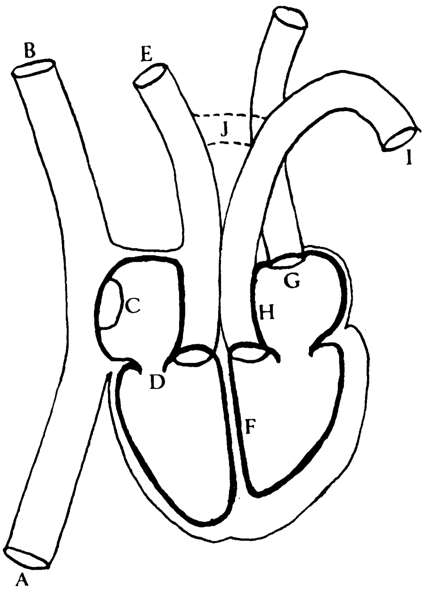

Fig 2 *Galenic cardiac physiology. For explanation see p 158 in part 2 (April).*

Galen had been obliged to take up in combating his adversaries, and the reason that linked function and form was deductive in nature. Nature does nothing in vain, therefore the pits on the right surface of the septum cannot be without purpose. No purpose could be conceived for such structures except the one that Galen had already thought of, and so this *must* be their function. These pores were seen not by the physical eye, but by the "eye of reason," a device often used in the history of anatomy, and one to which increasing attention was given in the renaissance. Although it was universally admitted that there could be structures in the body that were too small to be seen, there was an increasing scepticism about traditional ways of establishing their structure.

Such scepticism, and other doubts about Galenic doctrine, were essentially destructive, and were opposed by the Galenists. The uncommitted found little attraction in criticisms that did not replace with anything better what they attacked. In general we find that those who *did* successfully attack Galenic doctrine had some alternative system of belief about the body, on which they could stand firm while attacking the extensive structure of Galenism which, after all, underpinned the whole of contemporary medicine.

One such alternative was Aristotelianism. Another was religion, and it was a literal interpretation of the Bible that led Michael Servetus to both the theory of the pulmonary transit and to the stake as a heretic. Servetus had been a medical student with Vesalius, and Guinter, their common teacher of anatomy, groups them together for their excellent knowledge of Galenism and the structure of the body. Vesalius attacked Galen on his own ground, as Galen himself had attacked others, but Servetus used and modified Galen's anatomy only to explain his prime theological problem: how does enough spirit enter the blood to account for the biblical fact that the blood is the seat of the Holy Spirit? Servetus argued that the left ventricle, traditionally the site of the elaboration of vital spirit and arterial blood from air and venous blood, was too small for the proper admixture of the blood and spirit. It seemed to him that the lungs were much more suitable—larger and with the blood vessels finely divided and more directly exposed to the outside air. The theological importance of the breath of God entering the body of man was the guide that led Servetus to an examination of structure, and it mixed strangely with the Hellenistic *pneuma* tradition of "spirit," with its quite different history.

At all events, Servetus's examination of structure led him to question the porosity of the septum of the heart, and it turned his attention to the size of the "arterial vein"—the pulmonary artery (E in fig 2). Why was this vessel so large, if its only function was to carry enough blood to nourish the lungs, as Galen had said? Why did the lungs need so much more venous blood than the heart itself, served by the diminutive coronary vein? Did not rather all the anatomical signs point to the fact that blood entered the lungs in some quantity and with some force, engaging the divine spirit and carrying it down again to the heart and thence to the body in the arteries?

This was in essence little more than a shift of emphasis in Galenic physiology, which Servetus was *using*, not attacking. It did not matter to him whether the septum leaked a little blood from right to left, and he admitted that it might. Servetus's emphasis on the blood led him into a position that had some features in common with that of the Aristotelians, a position from which Galenism could also be modified. We shall look later at the role of Aristotelianism in these discussions about bloodflow but must first consider how Servetus's *method* compares with that of his predecessors and contemporaries. Because the blood contained the most important element of man, it was unthinkable that the rational faculty was in the substance of the brain, which Servetus regarded as cold and senseless. The important structures were of course the blood vessels in the brain, where the traditional Galenic *rete mirabile* played a partly traditional role. Servetus argued, in a neo-Aristotelian manner, that the blood vessels entering the brain ultimately became nerves and emerged from the brain to descend to the body. While in the brain, the vessel-nerve was an intermediate, different kind of vessel, comparable to the vessels in the lungs that connected the incoming pulmonary artery to the outgoing pulmonary vein, but which were neither artery nor vein.

So, like Galen, Servetus had an idea so important that he could not avoid its consequences. The importance of the blood made necessary the existence of the new kind of vessel that communicated across the lungs and the brain. This was seen by the eye of reason, which confirmed the existence of invisibly small structures. Other anatomists were beginning to use their physical eyes to deny such invisibly small structures as the pores in the septum, but this technique was foreign to Servetus's purposes. Nevertheless, it remained something of a paradox that those anatomists who denied the pores of the septum on the grounds that they could not be seen were obliged to invent similar pores in the lungs to explain how blood appeared in the pulmonary veins and left ventricle. Those for and those against the pores in the cardiac septum could equally call on the common belief that the liver had invisibly small pores communicating between the portal and caval veins. The paradox remained, and we shall see in a later article how Harvey remained sensitive on the topic of anastomoses and other small communicating channels.

Sevetus[12] and all but a handful of the edition of his book were burnt at the stake in 1553. The survival of only three copies down to the present makes it uncertain how much influence this book on the reconstruction of Christianity had on later anatomical writers who described the pulmonary transit. Because no printed version of Ibn al Nafis's hypothesis of the pulmonary transit appeared in the renaissance, there is a similar historical question on the possible influence from Ibn al Nafis to Servetus. There is a slight possibility of oral transmission through the anatomist Massa,[13] whose unorthodox ideas on the heart and bloodflow we have already noted.

Cardiac valves and the quantity of blood

The growing scepticism about the existence of the Galenic septal pores was extended also to another cardiac structure, the mitral valve. Galen had said that this structure had admitted the flow of air, or the quality of air, *into* the heart and also the *exit* of sooty wastes produced from the concoction of vital spirit in the left ventricle. Arterial blood also moved up the venous artery from the left ventricle to supply the lungs. The valve thus allowed a two-way flow, and was not acting in the way we understand a valve to act. Some modern historians call Galen's mitral valve "incompetent," but this is a modern interpretation and almost implies a pathological state; in fact, this valve in Galen's view acted like all other valves, allowing a certain amount of back-flow.

An important point was *how much* blood flowed in the "wrong" direction across the mitral valve, and indeed how much flowed across the cardiac septum. It would be possible to draw up a list of criticisms of Galen's physiology based on quantitative considerations, leading up to Harvey's estimate of the amount of blood ejected at each beat of the heart, which forms part of an argument that is so convincing to modern ears. But it was not necessarily so convincing to Harvey's contemporaries, and such a list of related arguments would be misleading if it suggested a change from "qualitative" to "quantitative" physiology.

We can look briefly at how such arguments were used. Galen was aware of the deductive nature of his argument in establishing the existence of the septal pores (described above) and indeed he criticised improper use of the eye of reason technique by others.[14] He felt he had avoided the dangers of such arguments by supporting their results by sense observation. In the case of the septal pores he claimed to have confirmed their existence by the observation that the vena cava entering the heart was larger than the arterial vein (pulmonary artery) leaving it for the lungs. The vena cava carried more blood than the arterial vein, the septal pores having removed a certain quantity. Quantitative criticisms of Galenic physiology at this level were made by Ibn al Nafis,[15] and Servetus argued from the comparative size of the arterial vein to the pulmonary transit: the arterial vein was too big merely to serve the lungs. The same argument was to be used by Colombo.

So by the middle of the sixteenth century there was widespread criticism of three features of Galenic cardiac physiology—the pores of the septum, the two-way mitral valve, and the large size of the arterial vein. With hindsight it is easy to see that all three point in the same direction: no blood crossed the septum, so the arterial vein carried *all* the blood needed by the left side of the heart, the arteries, and the body, and the competence of the mitral valve meant that the lungs were served only by this transit of blood across them. Yet it was not until Colombo that these three features were combined in this way. A pulmonary transit meant that the traditional sooty wastes from the left ventricle had to be ignored (there was now no route for them to escape) and it meant that the lungs now had to be served by their own production of vital spirit (which had previously arrived from the heart by the same route as the fuliginous vapours), or that the lungs generated all the vital spirit needed by the entire body. All this was a considerable, but not total, departure from pure Galenism, and it prevented many from elaborating the three criticisms of Galenic physiology into a coherent argument.

In such a position was Sylvius, arch-Galenist, teacher, and opponent of Vesalius. Convinced that Galen's anatomy represented the truth, and yet led by Galen's own advice to examine the human body studiously, Sylvius found that the body did not agree with the text. He extricated himself from this dilemma by adopting the not uncommon notion that the human body had degenerated in the interval between Galen and himself. (Galen of course had dissected only apes.) By these means he could explain how degenerate man had but five, not seven, bones in the sternum, but he could not explain why he did not find the septal pores in the heart of man. In his teaching he customarily omitted as too difficult the part of *De Usu Partium* that describes the heart and its pores. In dissection he adopted the novel practice of inflation to show the connection between the vena cava and right ventricle, between the right ventricle and the lungs, and between the left ventricle and aorta. He did *not* show the passage from right to left across the septum, nor did he attempt to describe the "normal" Galenic bloodflow from right to left: he simply ignored the pores.[16]

Vesalius had no such reservations about attacking Galen, and did so with enthusiasm. He could not see the septal pores and in the second edition of the *Fabrica* he expressed a doubt as to the function of the heart in this particular. But Vesalius was an anatomist and not a physiologist, and could not uncompromisingly deny the pores without destroying Galenic physiology. He had nothing to put in its place, so he did not pursue the matter.[17]

Colombo

Vesalius's successor at Padua, Realdo Colombo,[18] had no such hesitancy. He uncompromisingly set out the pulmonary transit, unlike Vesalius, and unlike Servetus did so in straightforward scientific terms. Moreover most of his anatomy is Galenic, without the emphasis on the blood that coloured Servetus's account. Thus he insists that the veins originate from the liver (in which we may contrast him to Vesalius as well as to Aristotle) and to such an extent that he denies, on embryological grounds, that the pulmonary artery—that is, the arterial *vein*—arises from the heart, deriving it instead from the vena cava. Likewise he has no time for the Aristotelian notion that the heart or the blood vessels are the source of the nerves. As Servetus had done, Colombo realised that the arterial vein was too big merely to afford nourishment to the lung in the Galenic scheme, and he declared that the blood moved across the lung and down to the heart once more through the venous artery, which did *not* also carry fuliginous vapours back in the opposite direction. Those who believe that the blood crosses the septum, said Colombo, "all err by a long way."[19]

The question of originality once more arises. It may well be that Servetus first looked for an alternative pathway for the blood as a result of Vesalius's inability to demonstrate the pores of the septum. Both had been students of Guinter before 1539, and no doubt Servetus had read Vesalius's remarks on the septal pores in the first edition of the *Fabrica*. On the other hand it is just possible, but unlikely, that by the time of the publication of the second edition, Vesalius knew of Servetus's views, perhaps through manuscript copies of the latter's work that may have been circulated from 1546 onwards. One such manuscript is known from before 1550[20] and such works may by the same token have affected Colombo's views. On the other hand, Colombo's work was not published until 1559, after his death, and it may well be, as his Spanish pupil Valverde tells us, that it was some years earlier that Colombo had arrived at the idea.

Valverde begins by describing his work under the guidance of Colombo, and as Pagel observes, it is reasonable to suppose that his description of the pulmonary transit is that of Colombo. This is also the view of Coppola, but it has been challenged by Guerra,[21] who from a study of the first, Spanish, edition of 1556 concludes that Valverde is describing his own discovery of the pulmonary transit and that this was used by Colombo. Valverde's work has generally been thought to have been derivative because the illustrations used in the various editions are mostly taken from Vesalius. Of the 253 Valvedean figures, only 15 are not taken from the *Fabrica*.[22] In fact the work assumes the character of an exposition of Vesalius's text and illustrations, with interpolated passages in which Valverde disagrees with Vesalius. There seems little reason to doubt that these disagreements are the result of his own experience when working with Colombo in Pisa, Padua, and Rome, and Guerra energetically pursues the claim for Valverde's originality. Valverde himself listed ten topics on which he disagreed with Vesalius, although several others may be found in the text. Neither Valverde nor his historian Guerra refer to Vesalius's text, and Valverde admitted that, like others, he found Vesalius's text so obscure as to be virtually unintelligible. One of the express objects of his own book was to write in plain language " . . . in the manner of a commentary on what I have seen in the corpses."[23]

There are several things, then, in which Valverde claims to be original, but none have the significance of his supposed discovery of the pulmonary transit. In discussing it, he describes his association with Colombo as limited to the single experiment, often repeated, of finding blood and not air in the pulmonary vein of the living and dead animal. A debased Galenic tradition presented this vein, the venous artery, as containing air only, moving from the lungs to the heart for the production of vital spirit. It is unlikely that Colombo repeatedly vivisected animals in this way without some idea of the significance of finding blood in the vessel, despite Valverde's claim that the idea of the pulmonary transit was his own.

In the relevant passage[24] Valverde uses the idea of pulmonary transit simply as an explanation of why blood is found in the pulmonary vein, for he is writing an anatomical and not a physiological textbook. If we too give most of our attention to the anatomical basis of his opinion we notice that he did not absolutely deny the existence of pores in the septum of the heart, for he believed it possible that some blood might cross the septum from right to left. Valverde makes no mention of the imperfect action of the mitral valve, which once admitted would have been inimical to his ideas.

Colombo also refers to the experiment of opening the venous artery in living and dead animals[25] and concludes that the blood invariably found there had moved down from the lungs, with air, to the left ventricle. His firm denial of the pores of the septum, and his remark on the large size of the arterial vein, both noted above, are not to be found in Valverde's account. For lack of further evidence it seems most likely that the accepted account of Valverde borrowing from Colombo is correct. Colombo claims the discovery as his own, and he makes other claims, not all of them justified. He saw that his discovery of blood in the venous artery of a living dog and his denial of the pores in the septum meant that Galen was wrong and that blood passed through the lungs. "Is Galen to be accepted as the Evangelist, and all that he has written to be thought of as true?"[26]

To summarise the position at this point in the evolution of ideas on the pulmonary transit, we can see that the historically important event was the denial of the pores of the septum of the heart. Without septal pores, but yet with blood in the arteries (which was universally accepted) and moreover in the venous artery (which was shown by experiment) it became necessary that blood moved across the lung from the right to the left side of the heart. Alternatively, admitting that some blood at least crossed the septum, the presence of blood in the venous artery still led to the conclusion that it arrived there from the lungs, if the suspect, Galenic, function of the mitral valve was denied.

Reception of the idea

The denial of the existence of the septal pores of the heart was a major attack on Galenic anatomy and physiology. How was the idea received in pre-Harveian thought? Fallopio denied it in a lecture in 1561, and in the same year Paré mentioned it approvingly in print. It was considered carefully by Vidus Vidius, and discussed, with some confusion and in relation to the horse, by Ruini. Even the Galenist Guinter came to believe in the pulmonary transit.[27] In all, the question was energetically discussed, and not a few came to anti-Galenic conclusions. In these anti-Galenists we see the influence both of their own researches and reasonings and of those of Aristotle. The old dispute between the philosophers and the physicians was by no means resolved, and Aristotle continued to be a significant figure well into the seventeenth century, not only in inspiring advance, but in securing its reception. We may take as an example of this debate a characteristic collection of opinions put together shortly before Harvey first announced the discovery of the systemic circulation. This is Knobloch's *Anatomical and Physiological Disputes*,[28] the tenth of which concerns the heart. The views of Vesalius and Colombo are noted, and Plater's opinions are identified with those of Colombo. Also mentioned is Botallus, who claimed that the blood moved from right to left ventricle not through septal pores but through a passage discovered by himself. This is the medical writer Botal, a pupil of Fallopio. His "anatomical observations" are a very small part of his writings, and the relevant observation is no more than a paragraph.[29] He disagrees with Galen's statements about the passage of blood across the septum and with Colombo's views, which he may not have understood clearly.[30] In attempting to follow Colombo's opinions during dissections, he anatomised a heart and found a "fairly apparent" duct from right to left auricle. This he regarded as a vein that nourished the arteries and vital spirit, and which he called the *vena nutrix*, assuming that it carried blood from the right to left ventricle, and that it was the only pathway of this sort for blood. He noticed that in man the passage was tortuous, sometimes more open than others, and beset with valve-like structures. In oxen, swine, and dogs he found it always open.

Clearly Botal was describing the small part of the *foramen ovale* that occasionally persists in the adult (at H in fig 2). It is also clear that he had not read his Galen properly, for the structure is described clearly enough in *De Usu Partium*.[31] As his seventeenth-century editor observes, Botal "straight away, with Archimedes, cried Eureka! but it was a Triumph before a Victory. . . ."[32]

More perspicacious was Julius Caesar Arantius who, while hesitating over the existence of the septal pores, described both the *foramen ovale* and the *ductus arteriosus* in greater detail, but modestly claimed only to be setting out in clear language things otherwise expressed by Galen, and to add a few details. His book of 1564 related strictly to the fetal state, and not to the adult, as did that of Botal. The *foramen ovale* between the auricles of the heart was seen as a device to make it possible for venous blood from the vena cava and right auricle to reach the left auricle, venous artery and lungs, for the formation and nourishment of the latter. After Galen, it was realised that in fetal life the lungs are not used, and that blood does not therefore reach them through the usual channels. Venous blood arrived at the lungs as suggested above, while the *ductus arteriosus* was seen as a channel from the aorta to the arterial vein (pulmonary artery) to supply the lungs with the arterial blood they would otherwise lack (J in fig 2).[33] (Arantius also described the *ductus venosus* of the hepatic end of the vena cava, apparently unknown to Galen.)[34]

Not entirely dissimilar are the views of F Ulmus, as reported by Knobloch and Crooke. He is said to have avoided the notorious pores by assuming that the arterial blood is generated in the adult spleen and that it passes *up* the aorta to the heart and thence to the lungs; he dismissed Colombo's ideas. Equally unorthodox were the ideas of Varolius. He raised the auricles of the heart to the status of separate chambers and referred to the heart as four-chambered, while Galen had called the heart two-chambered, thinking of the auricles as extensions of the vessels. Varolius also called the left ventricle the "middle" ventricle, as if in an attempt to explain away Aristotle's notion of a third ventricle. Each of the four cavities, continues Varolius, has its own function, and therefore its own motion, as may be seen in the living dog. The function of *both* auricles is to attract air for the formation of spirit, for venous blood in the right auricle needs spirit as well as the arterial blood in the left. All parts of the body are nourished by a proportionately correct mixture of venous and arterial blood, *both* of which take the heart as their origin.

It seems clear that this is an Aristotelian position forced on Varolius by the non-existence of the septal pores. He does not accept that blood can pass from right to left either through the septum or across the lungs, and he therefore has to construct a new scheme of physiology, in which there is a large element of symmetry. Varolius begins by asserting that the finest parts of the chyle in the intestines are taken up by both arteries and veins, and are delivered as imperfectly concocted blood to the right ventricle by means of the vena cava and to the left by way of the aorta. These symmetrical movements are achieved at a cost of reversing, at this stage, the flow of blood in the aorta as described by both Aristotle and Galen. They also meant ignoring the functional direction of the valves at the cardiac orifice of the aorta, the anatomy of which had spoken so clearly about this direction to all other anatomists, except Ulmus. After the concoction of perfect blood of both sorts by admixture with air in both ventricles (again implying a faulty valve in the right as well as the Galenic faulty valve in the left side of the heart) the direction of the flow in the vena cava and aorta is reversed, and the perfected blood flows out to all parts of the body.

There are useful examples in this scheme of the way in which anatomical and physiological ideas interact. Like so many others, Varolius doubted the truth of Galenic anatomy and physiology because he could not see one centrally important anatomical feature, the septal pores. Varolius was a practical man, an anatomical innovator, who distrusted the excessive faith in reason by which Galen justified the existence of pores he could not see.[35] Varolius's emphasis on observation was related to his interest in problems of perception and his work on the sense organs,[36] but his own error in physiology (the ebb and flow in the blood vessels) was, nevertheless, due to a process of reasoning that was similar to that which convinced Galen that the septum was pervious. The anatomical evidence, in this case the structure of the heart valves, was over-ruled by Varolius in favour of deductive reasoning from supposedly unshakable axioms and a scheme of physiology made intellectually attractive by its symmetry. "Nature does not multiply entities unnecessarily" was Varolius's axiom and from it he deduced that each major vessel (aorta and vena cava) had *two* motions in carrying blood alternatively up and down. This was economy on the part of Nature, who would otherwise have been obliged to create two more vessels for these motions.

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