

The thorax in history 2. Hellenistic experiment and human dissection

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The first anatomical revolution occurred in Alexandria in the third century before Christ. To that period we can trace the continuous historical line of our own ideas on the structure and function of the body, important among which are those on the thorax. For the first time, the human body was systematically explored in an attempt to understand its structure, and, with some notable errors from animal anatomy, the only source for 'human' anatomy in the preceding period, these anatomical ideas are recognisably similar to those of to-day. The physiological ideas of the Alexandrians, on the other hand, are strikingly different from ours, and their subsequent transformation will be examined in later articles.

Human dissection

The most important single reason behind this first anatomical revolution was the introduction of systematic dissection of the human body. It was suggested at the beginning of the first article in this series (*Thorax*, 33, 10–18, 1978) that human dissection has been historically very rare and that there were normally a number of taboos operating against it. We must briefly consider then why it was that the human body could be dissected in Alexandria.

Alexandria was the city of Alexander the Great and shared fully in the cultural and commercial exchanges of political empire. A cosmopolitan population, the mixture of Hellenistic and Egyptian culture, and the patronage of the arts and sciences by the Ptolemies all contributed to a cultural ferment. The changes that made Alexandria the centre of Hellenistic culture after the death of Alexander meant that no single system of philosophy or belief held a dominant position, nor were its taboos universally accepted.

Apart from such general considerations, there are a number of particular reasons why human dissection should have flourished. The opening of

the dead body was essential to the ancient practice of embalming, an Egyptian technique well known to the Greeks. The Greek philosophers, Plato and Aristotle, emphasised the distinction between soul and body:¹ it was the immaterial soul that survived the death of the corporeal body, and the soul, sharing no characteristics with the body, could not be affected by the postmortem mutilation of the body; there was no quasi-material after-life in human form, as so many cultures believed. In a word, the old religious taboos no longer applied.

Of fundamental importance in the development of human dissection in Alexandria was the existence of a medical school (or schools). Even in the absence of specific cultural taboos, the dissection of the body of a person recently dead naturally excites a feeling of revulsion; only in a medical school, where anatomy is considered a basic medical science and becomes an established discipline, is there sufficient mutual support within a group to preserve an unpleasant practice, a sort of professional rejection of the normal taboos. Human dissection was a *teaching* device as well as a research tool.

Also associated with the development of medical schools were medical and anatomical texts. Galen² tells us that the ancient method of teaching anatomy—he was thinking of the Hippocratic period—was oral, when the father (or master) taught his sons (or apprentices) within the family group over a period long enough for the assimilation of the great detail. Only when this system began to break down and adult men were admitted into the circle to learn anatomy in a shorter period was it necessary to write down the anatomy. Perhaps this increasing formalisation of teaching was becoming evident by Aristotle's time, for the first textbook of anatomy is said to have been written by Diocles of Carystos, a contemporary of Aristotle.³ Many of the anatomical texts up to the time of Galen (second century AD) were

school textbooks, or at least the texts of professional anatomy teachers. A written tradition, of course, is open to detailed and precise modification, and Galen's own treatment of the work of his predecessors is the beginning of textual and anatomical scholarship, upon which later developments depended.

A natural result of teaching within a school, as opposed to a father-son line of oral instruction, is, in addition to texts, a comparatively large number of students with similar ideas. Future teachers, chosen from the students, would perpetuate these ideas alongside the texts, so that the physical school becomes also a 'school of thought'. Aristotle's Lyceum became a school of peripatetic philosophy, opposed to others, like the atomist or stoic. In the same way the medical schools developed traditional ideas: from theoretical positions already available in the Hippocratic corpus, and in parallel with the medical schools that had already been in existence for two or three centuries on the periphery of the Greek world, there developed in Alexandria, during the period we are discussing, a number of medical 'sects' with profoundly different views on the usefulness of anatomy in medicine. The Dogmatists or Rationalists, inclined to natural philosophy, held that it was possible in principle to understand the processes going on inside the body, and that therefore the physician was justified in intervening in these processes to put right what had gone wrong in illness. As function was closely related to structure, it followed that anatomy was a fundamental medical science. It is possible that this attitude was reinforced by the observational, empirical, and inductive methodology that Aristotle had announced and put into practice in his zoological works.

It appears that the Rationalists of Alexandria took this methodology one step further and practised not only dissection, to discover human anatomy, but vivisection,⁴ to discover the function of the human body. In other words, they introduced *experiment* into the descriptive and observational method. Both dissection and vivisection were opposed by the Empiricists,⁵ who from Hippocratic times had believed that the processes of the body were ultimately incapable of explanation. The business of the physician was not, therefore, to intervene but to observe; empirical medicine emphasised prognosis based on case history and treatment based on regimen. The non-investigative empirical physician, rejecting the need of a knowledge of function, had no need of knowledge of structure, and he held not only that anatomy was unnecessary but that the means of

acquiring anatomical knowledge—dissection—was disgusting and unnatural. It was, moreover, misleading, since the organs of the body changed in death. It was undoubtedly to see the organs of the *living* body that the Rationalists employed vivisection, a technique that the Empiricists considered inadmissible on the grounds of cruelty. The Empiricists argued that the only form of anatomical knowledge necessary and proper to a physician was that gleaned 'accidentally' from wounds.

The influence of Aristotle

The question of the extent of Aristotle's influence on the Alexandrian experimenters is not agreed among historians, but a brief discussion of the topic will serve to highlight some important issues and to introduce the achievements of the Alexandrians themselves.

Wellman and Jaegar argue that there was a considerable line of influence from Aristotle through Diocles,⁶ whom we have already met as the author of the first anatomical textbook. If it is indeed true that Diocles thought of himself as a follower of Aristotle, then his book on human anatomy might well have been designed to fill the most obvious gap in Aristotle's biological works. The fragments of Diocles' work that survive show that his anatomy was in fact derived from animals, and it may be that, like Aristotle, he was unable to dissect the human body and relied on a methodology that consciously extrapolated from comparative anatomy to human. All this, however, is supposition, and all we can say with confidence of Diocles is that his treatment in general is like that of Aristotle, and like Aristotle he placed the soul in the heart. On the other hand, some important physiological and anatomical ideas of the Alexandrians and some of their wider beliefs are quite opposed to Aristotle, and Steckerl⁷ argues that his influence has been over-emphasised.

Whether or not a direct transmission of Aristotelian ideas can be identified, there is no doubt of the background importance of his philosophy. His argument that even terrestrial objects were worthy of the attention of a philosopher was new to Greek science and a turning point within it.⁸ His programme of analysing the whole natural world encouraged his successor, Theophrastus, to work on plants, at the description of which Aristotle had stopped short, and led his student, Clearchus of Soloi, to write a book on the anatomy of the human bones and muscles, another gap in Aristotle's world picture. Clearchus was contemporary with the first of the Alexandrian

anatomists and may have had access to human material in Alexandria. Certainly Aristotle's emphasis on the primacy of the senses in scientific investigation must have greatly encouraged the development of human dissection in Alexandria.⁹ (We have already seen how Aristotle's philosophy displaced some old taboos.) Although Aristotle's method was in a sense empirical (as opposed to the deductive system of Plato) it was part of a highly rational attempt to understand the natural world. It was rational in seeking to establish the *causes* of things, and this was an attitude that appealed to the medical Rationalists of Alexandria.

This rationality of Aristotle and others lay in uncovering the plan according to which nature had been put together. Perhaps the first appearance of this rationality appears in the 'Hippocratic' work on the heart, *Peri Kardies*, the author of which admires the skill with which the valves of the heart have been constructed. *Peri Kardies*, better known under the Latin title *De Corde*, is probably closer in time to Aristotle than to Hippocrates. By then it was accepted that the *reason* employed by Nature the craftsman, or the demiurge who, Plato said, created the body, was of the same kind as human reason, and man could, therefore, in principle understand how the natural world had been constructed. Anatomy now had a new function: it was no longer simply a medical affair, useful in understanding the structure and function of the body, and useful in surgery; it was also a philosophical exercise in learning how the body was constructed.

The results of human dissection

The major achievement of the Alexandrians was the discovery of the central nervous system. Of course, as we have already seen, the brain, spinal cord, and nerves had already been recognised anatomically, and some dim awareness of the motor and sensory powers of the brain had been the cause of a traditional placing of at least part of the soul in the head. But the Alexandrians knew that the central nervous system was *the* organising centre of the body; they distinguished between motor and sensory nerves, and we have every reason to suppose that they experimentally sectioned nerves in the living animal—perhaps, indeed, in living man—and learned from the result the function and distribution of the nerves. Discoveries thus made by experimental vivisection were taught by the descriptive anatomy of dissection.¹⁰ The central nervous system is not of direct consequence to the history of the thorax, except that Galen, in developing the work of the

Alexandrians, made some dramatic and sophisticated experiments sectioning the nerves controlling the motions of respiration. Its importance for our story is that the discovery of the central nervous system at once threw into relief the traditional debate about the most important organ of the body, the seat of the soul.

Quite apart from the other influences of the Aristotelian philosophy that we have discussed, a major influence was that Aristotle had said that the heart was the seat of the soul, the organising centre of the body. This position became increasingly difficult to maintain as the function of the brain and nerves became clear. The nerves were now distinguished from the other fibres of the body; *neura* became a technical term meaning 'nerves' only, and it was recognised that only *neura* had a sensitive and motor function. Yet so great was the influence of Aristotle that some anatomists attempted to reconcile Aristotle's non-nervous *neura* of the heart (regarded as the organising centre) with the new anatomy and physiology. Thus Praxagoras, who is placed by some historians in a direct line of influence from Aristotle and Diocles to the great Alexandrians, Herophilus and Erasistratus, claimed that the arteries, arising from the heart, finally became too narrow to admit blood and became nerves. Since the work of Herophilus and Erasistratus exists only in fragments¹¹ we cannot tell what directed their attention to the central nervous system; most probably it was a continuation of older Greek work on the sense organs, and particularly the eye. Some of this interest may have been originally generated as a result of philosophical problems of perception. We have already noticed a previously unrecognised addition to our knowledge of Herophilus's work on the optic nerves in a passage of Chalcidius,¹² and it is possible that he generalised, from this and other examples of the connections between the sense organs and the brain, to the statement that the brain is responsible for *all* sense and motion.

Whatever led Herophilus to these ideas, it was clear enough that the heart, the traditional seat of the soul and the prime organ of the thorax, could never be the same again. Two other discoveries just before or at the beginning of the Alexandrian period further transformed ideas about it and the pattern of blood flow through it. The first of these was the final clarification of the distinction of arteries and veins. While earlier authors had some glimmering of this, a striking difference between the two sets of structures was made by Praxagoras, who derived the veins from the liver (which was to be Galen's view) and said that the arteries

contain only air or spirit, *pneuma*, an opinion shared by Erasistratus and bitterly attacked by Galen. So the difference between arteries and veins was functional as well as structural. Herophilus said that the arterial coat was six times as thick as the venous, and Erasistratus, quite free from any ambiguities between nerves and other fibres, and between arteries and veins, elevated all three types of structure to the status of three great systems serving the body. The veins supplied nourishment, the arteries vital spirit, and the nerves psychic spirit; each organ of the body was actually composed of the fine terminations of the three kinds of ramifying vessel.

The second important discovery of the pre- or early Alexandrian period was that of the cardiac valves. We have seen that these structures are described in the work *De Corde*, which was once attributed to Hippocrates but which was probably written after Aristotle, perhaps in Alexandria. It is in the nature of a valve that it allows only a unidirectional flow, and this at once imposed severe constraints upon traditional ideas of the movement of blood and spirit through the heart. We have seen that these ideas are somewhat vague in the existing texts, but what is clear enough to us is that some symmetrical relationship was held to exist between the lungs and the heart, blood and air being exchanged on both sides. But the valves changed all this, those of the vena cava on the right 'entering', and those of the aorta on the left 'leaving' the heart.

These two discoveries involved the demise of the traditional fundamental pair of blood vessels, anciently assumed to run throughout the length of the body with symmetrically disposed branches to the organs. The discovery that one of these vessels was a vein (the vena cava) and one an artery (the aorta), the assumed origin of the vena cava from the liver and the aorta from the heart, and the assumed function of the arteries of carrying spirit, not blood, all combined to destroy the ancient symmetry. The picture was particularly complicated in relation to the vessels between the heart and the lungs: the vessel that arose from the heart on the same side as the veins looked like an artery but was considered to have a venous function as part of the great nutritive system of liver—vena cava—heart—veins. Correspondingly, the vessel between the heart and the lungs on the left, the arterial side of the heart, looked like a vein but had to have the arterial function of the great respiratory system of lungs—left ventricle—aorta—arteries. The names 'venous artery' and 'arterial vein' thus came into existence during the Alexandrian period.

Herophilus and Erasistratus

Against this background we may briefly inspect what was said about the thorax and its origins by the two greatest of the Alexandrian anatomists and physiologists, Herophilus and Erasistratus. It was Herophilus who said that arteries had tunics six times as thick as those of veins, and he was consequently struck by the arterial nature of the 'vein' connecting the heart and lungs and by the venous nature of the 'artery'. Rufus of Ephesus¹³ tells us that Herophilus introduced the terms 'arterial vein' and 'venous artery' for these vessels, although Galen appears to claim them as his own invention.¹⁴ Galen also tells us that Herophilus wrote 'carelessly' about the cardiac valves, perhaps in retaining some confusion about the 'nervous' fibres associated with the valves; we may assume at least that Herophilus recognised the functional direction of the valves. Thus in the fourfold motion of the lungs (which uniquely in the body had a motion independent of the nerves) air was drawn into the lungs, from the lungs to the heart and body and back again, and lastly the air was expelled. We can probably assume that the incoming air passed down the venous artery (pulmonary vein) into the heart, and thence via the aorta to the body. In the aorta and arteries this air or spirit was mixed with blood. Given the functional direction of the valves, however, we cannot see how this air was returned to the heart and lungs; nor can we be certain that Herophilus allowed the cardiac valves to work 'properly' (in our sense). The force of traditional ideas was such that many schemes of physiology contain allowances for them despite the discovery of the valves. Thus the Hippocratic *De Corde* allows that the valves on the right side of the heart do not close completely, allowing in some air from the lungs and maintaining an ancient symmetry of blood and air exchange. We shall see that Galen's ideas on bloodflow are an imperfect compromise of old ideas and new discoveries, allowing an imperfect closure of the valves on the left of the heart. Lastly, it is possible that we see the persistence of old ideas in Herophilus' notion that spirit enters the body not only by way of the heart but from all over the body.¹⁵ This may be the idea, derived from Empedocles, that tubes, or arteries, have open mouths at the surface of the body, drawing in air. Herophilus' study of the pulse in diagnosis and physiological theory seem to have been an innovation. While the arteries originated in the heart, Herophilus said he could not be certain of the source of the veins.¹⁶

In contrast, Herophilus' younger contemporary,

Erasistratus, located the origin of both veins and arteries in the heart. He was in early life associated with the Aristotelians, and it may be that this anatomical suggestion is a sign of peripatetic influence.¹⁷ On the other hand, he believed in a form of the atomic theory, involving a belief in a discontinuous vacuum and a rejection of 'hidden' causes. Nothing could be further from the teleologically organised plenum that was Aristotle's world picture.

Erasistratus seems to have been more interested in the working of the body than was Herophilus, whose achievements were primarily anatomical. The fragments of Erasistratus' work on the physiology of the thoracic organs are fortunately more detailed than those of Herophilus. Consistent with his anti-Aristotelian atomism was his belief that the body did not have (as Aristotle had said) an innate *pneuma*, but that the ambient air (spirit or *pneuma*) was drawn in during inspiration, passing through the 'primary arteries'¹⁸ (the bronchi) to the lungs, from the lungs to the heart, and from the heart to the body. This is an elaboration of the traditional idea of the arteries, heart, and lungs as a single respiratory system. So taken by this idea was Erasistratus that he insisted that the arteries contain only *pneuma*, unmixed with blood.¹⁹ Once in the body, the *pneuma* underwent two stages of concoction: in the left ventricle it became vital spirit, which filled the arteries, and in the arteries of the brain it became psychic spirit.²⁰ Erasistratus simplified Herophilus' notion of the heart, regarding it as a two-chambered, not four-chambered organ, the auricles being merely ear-shaped expansions of the vessels at their connection with the ventricles. This made it easier to regard one half of the heart as respiratory and the other as sanguineous or nutritive. As there was no communication between the two systems in the heart or lungs, Erasistratus was in difficulty in explaining how blood emerges from a wounded artery, which he considered contained *pneuma* only. He thought that the finest branches of the veins, too narrow to admit blood, anastomosed with the finest branches of the arteries, and that in certain circumstances, as when the arteries were damaged and their *pneuma* escaped, blood was drawn into the arteries from the veins by the resulting vacuum.

Galen²¹

Some time between the period of Herophilus and Erasistratus and that of Galen, who was born about 129 AD in Pergamon, the practice of human dissection as a teaching and research practice

came to an end in Alexandria. The Ptolemy who reigned in the second half of the second century BC expelled the physicians, which perhaps hastened the decline of teaching. Rufus of Ephesus, writing at the time of Trajan, described human dissection in retrospective terms and had to be content to dissect the pig, although recognising that apes were more similar to man.²² Although some Hellenistic texts²³ mention Apollonius of Memphis as a dissector and a follower of Herophilus (he antedated Galen) it is clear that by Galen's time the practice had ceased. Galen himself was in the midst of a revival of Greek studies that began in the Roman world some 50 years before he was born.²⁴ The part played by Galen in searching out the spirit of Greek medicine was his reverence for Hippocrates, his anxious pursuit of the pupils of the famous Greek teachers of anatomy, and, it must be admitted, his pretence that he, like Alexandrians, had had the opportunity to dissect the human body. The only human material routinely available to him was the skeleton while he was learning anatomy in Alexandria.²⁵ Otherwise, it was only fortuitous circumstances that furnished him with glimpses of the anatomy of the soft parts, and indeed much of his insistence on a systematic training in comparative anatomy and the dissection of animals reflected the need to prepare the mind for occasional access to human material. Galen's literary energy was immense, and a very large proportion of his numerous medical works survive; his influence was enormous and for a millenium and a half he was revered as 'The Prince of Physicians'.²⁶

Galen's system of physiology, as far as it relates to the thorax, was an amalgam of his own discoveries and reasoning, and older ideas. A partial survival of the old idea of the body's fundamental pair of vessels is Galen's description of the vena cava as a long, continuous vessel arising from the liver. The liver was the starting point of the body's physiological processes, the site of the 'first coction' where the incoming food, transformed to chyle by the action of the stomach and intestines and carried to the liver by the portal vein, was turned into blood, the food of the body. The body as a whole absorbed this blood slowly by the process of *assimilation*, literally 'making similar'—a process in which the Aristotelian qualities of the blood were so disposed to convert part of the blood into body substance. In other words, each tissue or 'similar' (homogeneous) part took from the blood what was necessary to it, leaving a small proportion of residue to be eliminated. The entire venous system was thus like a

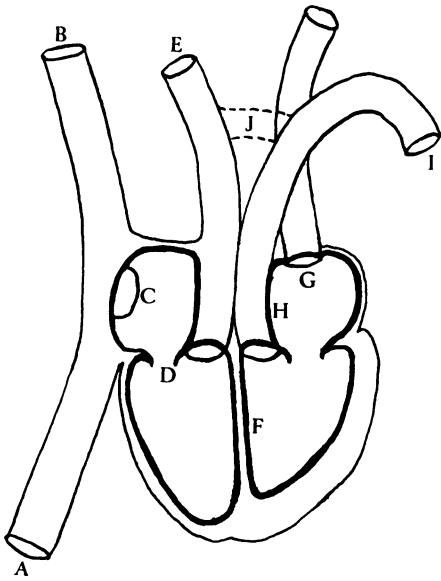


Fig. 1 Galenic cardiac physiology. For explanation see text.

tree,²⁷ the trunk of which was the vena cava, planted in the liver and supplying blood to all parts of the body with a slow, unidirectional motion through its branches.

It follows that for Galen, unlike other writers such as Aristotle, the vena cava did not arise in the heart, nor indeed did the heart interrupt the structure of the vessels as it passed along the body, for the vena cava merely inosculated with the heart by means of the intermediary right auricle, which Galen regarded simply as a sinewy extension of the vein. This arrangement is shown in the diagram (Fig. 1), where AB indicates the vena cava arising from the liver and passing the heart, and C its opening into the right auricle. The entire venous 'tree' is in line with the older idea of the 'nutritive' (venous) system as opposed to the 'respiratory' (arterial), and it enabled Galen to agree with the old-fashioned accounts (which we met in the first article) of the vascular system given by his idols, Hippocrates and Plato,²⁸ and to reject those who opposed them, including Erasistratus. In fact Galen's rejection of Erasistratus' claim that the veins, like the arteries, arise in the liver is illuminating. Erasistratus was aware of the valves that point into the heart at the attachment of the vena cava (we are now considering, with Galen, the heart as a two-chambered organ) and which govern the flow of fluids *into* the heart. How, asks Galen, can the heart be the centre of the venous system when the blood, the *raison*

d'être of the veins, is produced elsewhere (the liver) and carried *to* the heart? Galen concluded that the vein-producing and vein-controlling faculty must be located in the same place as the faculty that produced and controlled the blood, for otherwise nature would be multiplying principles in vain, which she never does. There is little *morphological* difference between a cardiac origin and hepatic insertion of the vena cava on the one hand and a hepatic origin and cardiac insertion on the other. Galen had in mind a teleological and functional conception of a liver—vena cava—heart—veins body arrangement, the venous 'tree' that has to be translated into anatomical terms. This is one example of a very general occurrence in the history of anatomy, namely, that physiological considerations very often determine anatomical statements.

Finally, there are technical reasons why Galen may have been encouraged to think of the vena cava as a long, continuous vessel. Unable to dissect the adult human body, he was obliged to use apes. It is possible that he and Aristotle were able to dissect human fetal material; in some apes and in the young human, the vena cava does have the appearances of a straight, continuous vessel passing through the right auricle and thus inosculating with the heart (Fig. 2).

Thus the body was supplied with blood through the branches of the vena cava arising above the point B in Fig. 1. As observed, each tissue took its proper aliment, the substance that resembled it most, from the blood. Yet there was one exception. The lung (always spoken of by Galen as a single bilobed organ),²⁹ constructed of exceptionally light and frothy substance, needed very light and subtle blood for its nourishment. Ordinary venous blood direct from the liver was too heavy and coarse, and Galen therefore supposed that that part of it destined for the lung underwent a second concoction in the right ventricle of the heart, which it entered through the opening of the vena cava into the right auricle (C in Fig. 1) and through the valve (D in Fig. 1). This preparation of the blood was the sole function of the right ventricle, executed by a specific 'faculty', a name Galen always used for a unique biological process about which little else was known. After concoction this blood was supplied to the lung through the vessel E (the pulmonary artery), which Galen considered to be a vein because it carried venous blood. He adopted the Alexandrian name of 'arterial vein' because he saw clearly that the vessel had an arterial structure. Galen did not accept that this structure was anomalous but argued that the thicker coat

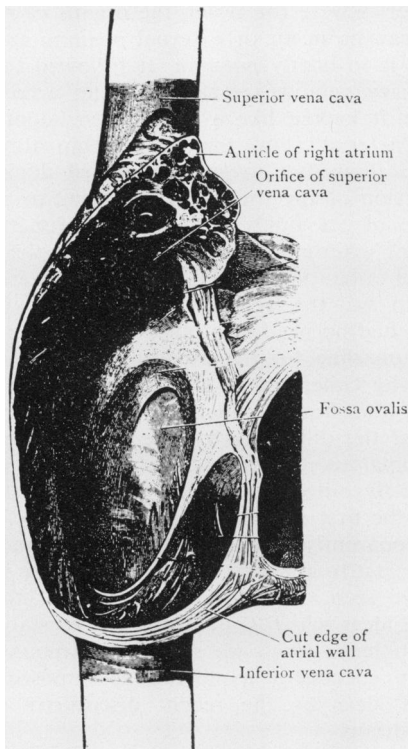


Fig. 2 The vena cava seen as a continuous vessel passing through the heart (modified from Cunningham's Manual of Practical Anatomy, reproduced by permission of the publishers).

of the vessel was designed to prevent the escape of the highly rarefied venous blood it contained.

In this way the whole of the body was supplied with nourishment. Yet, in accordance with traditional ideas, Galen held that the body must not only be nourished but vivified; it had to be governed not only by a nutritive faculty but by a vital faculty, giving heat, life, and motion. We may recall the fundamental physiological observations of the living and dead body with which this series of articles began, and also the resultant hierarchy of living principles or souls formulated by Plato and Aristotle. The soul responsible for vivication, heat, and motion was the inspired air or spirit-soul, and the system serving it in the body was the respiratory, that is, the arterial. We have described above how by Galen's predecessors the lungs, heart, and arteries were considered as a single system. Galen accepted this, but with a very important reservation: he insisted that the arteries contain blood, not simply spirit. He wrote a book³⁰ to refute Erasistratus on this point and, using the

Alexandrian vivisectional experimental method, he proved his case by experiment.³¹ He ligated an exposed artery of an animal in two places to prevent subsequent inflow of blood from the veins (the Erasistrateans' argument) and opened the artery between the ligatures. Of course he found it was full of blood and, like others, he was able to distinguish between arterial and venous blood by their colour and the force with which they flowed in their vessels.

But now Galen faced a difficulty. The two vascular systems were quite separate, one in the traditional fashion concerned with nutrition, the other with the respiration of spirit. He insisted that the arteries contained blood but denied transference of blood from the finest branches of the veins to those of the arteries in the way described by Erasistratus. There was for Galen no way of getting blood from its only place of production, the liver, into the arteries. With hindsight we can see it would have been a simple matter for him to have supposed that blood crossed the lungs and entered the heart through the pulmonary vein (the venous artery), but Galen had already denied a venous-arterial exchange of blood. To have postulated one in the lung would have been, in addition, to obscure the traditional distinction between the nutritive and respiratory systems. Moreover, the lung, like all parts, absorbed the blood coming to it as nourishment.

In order to avoid this difficulty, Galen postulated the existence of pores in the interventricular septum of the heart, so that a small quantity of venous blood could be transferred to the left ventricle at F (Fig. 1). The left ventricle was a traditional seat of the soul in Greek medical thought (compare *De Corde*), and Galen placed it in a Vital Faculty, which transformed the incoming venous blood into arterial blood, which carried vital heat to the body through the arteries. The concoction that produced arterial blood necessarily required the inspired air or spirit of the outside world. Galen urged that air in substance, or its insubstantial quality, passed down the venous artery G (Fig. 1) from the lung to the left ventricle. This life-bearing *pneuma* was transformed in the left ventricle into vital spirit, *pneuma zotikon*, the essential component of arterial blood. As in all concoctions, there were residues to be expelled, here 'fuliginous vapours', whose only route of escape was back up the arterial vein to the lung and outside world.

THE CARDIAC VALVES

Yet, in solving his first difficulty in this way, Galen found himself with another. Spirit passed down

through the venous artery into the left ventricle through the valve now called the mitral. It was clear to Galen and others that the functional direction of this valve is into the heart, but Galen was obliged to allow passage in the reverse direction to the escaping fuliginous vapours. Moreover, the lung, like all parts of the body, needed arterial blood, which could reach it only from the left ventricle in opposition to the natural direction of the mitral valve.

So Galen had three different substances, arterial blood, spirit, and sooty wastes, moving in two different directions across a valve whose natural direction favoured the motion of only one of them and that the least substantial—spirit, or the quality of air. This part of Galen's cardiac physiology drew the criticisms of later natural philosophers and of historians. It caused Harvey to cry 'Good God! How do the mitral valves hinder the return of air, and not of blood?'⁸² But Harvey knew what a valve was, and those historians who discuss the 'incompetence' of Galen's mitral valve are anachronistically reading back to Galen their own knowledge of valves. Galen's attention was given to the flaps of the valve, the *membranarum epiphyses*, not to the whole structure of the valve. Every concoction, every exchange of materials in the body was accompanied by some residue, some superfluity, for no substance ultimately derived from food was entirely pure. It followed that *all* the cardiac valves allowed *some* reverse flow, and the mitral valve was particularly notable in this respect because of the intensity of the concoction in the left ventricle, and because it had *fewer flaps*. Galen had no other notion of what a valve was other than the flaps of the heart. Although he repeatedly used the analogy of a bellows to explain how the heart attracted substances, they were valveless bellows. Not until shortly before the time of Harvey were valves well enough known in other fields (in water mills, in pumps of fire engines, in the veins, and in the intestine) for the 'incompetence' of Galen's mitral valve to stand out in contrast. Although Galen seems only to have described the mechanical reasons for the opening and closing of the flaps, the forces impelling the passage of the fluids through the valve were the purely biological Faculties of attraction, retention, and expulsion, which were entirely non-mechanical. So Galen's whole idea of the movement of the fluids of the heart was *sui generis*, and he does not deserve all the censure normally levelled at him.

THE SPIRITUAL AND ANIMAL ORGANS

The left side of the heart, the pulmonary vein, and

the arteries were for Galen the organs of respiration, drawing in air or external *pneuma* and converting it to bodily *pneuma*. It followed that the pulmonary vein was regarded as an artery, and because it looked like a vein Galen adopted the name 'arterial vein' for it. Its thin tunic, he argued, allowed it to be compressed during the contraction of the thorax in breathing to aid the passage of its fluids. The normal function of the thick arterial coat was to transmit the active wave of dilatation, which Galen considered the pulse to be; the venous artery, moved by the thorax, had no need of a pulse or thick tunic.

It is puzzling for the modern reader to understand why Galen did not simply allow that blood crossed the lungs, which would at once have removed the difficulties of the perforate septum, the anomalous structure of the pulmonary vessels, and the 'incompetent' mitral valve. This step was indeed the first advance from Galenic physiology, made apparently independently three times before Harvey, but to ask why Galen did not take it is, as we have seen, to ignore the power of the traditional ideas which Galen took to be established. The problems which we see in his account were for him successful modifications imposed upon the old ideas by the recent discoveries of the Alexandrians.

In contrast, Galen's ideas on the nervous system did not depend on ancient ideas and on the revered Hippocrates but on comparatively recent work, much of it based on vivisectional experiments, both his own and of the Alexandrians. There was no weight of traditional ideas to labour under, and Galen's description of the nervous system is much more successful in modern eyes than that of the heart. Broadly, the central nervous system for Galen represented the highest category of the traditional hierarchy of three-fold governance of the body, the lower two being the nutritive and the vital. Just as the vital faculty of the heart and arteries depended on the nutritive, so the vital faculty provided material for the rational or 'animal' faculty of the brain. Arterial blood ascended through the carotid arteries to the *rete mirabile*, a network of arteries which Galen (and the Alexandrians) found above the basilar bone of the skull of certain domestic animals and attributed to man. In it the finely divided blood, said Galen, underwent a second concoction, with air drawn in through the nose into the ventricles of the brain, to produce the second of the bodily spirits, *pneuma psychikon*, 'animal spirits'. This *pneuma* filled the substance of the brain and nerves and served the power of motion and the faculties of sense.

By dissection and vivisection Galen traced out the course of the cranial and spinal nerves and showed how such anatomical knowledge was essential to medicine. It is his most powerful attack against the Empirics, and he illustrates it by the story of a patient who had fallen from his conveyance on his way to Rome, damaged the vertebrae at the bottom of the neck, and lost the use of three fingers. The Empirics applied their remedies where they found the symptoms. Galen treated the origin of the nerves at the vertebrae and effected a cure.³³

Another story of which Galen was proud was that of his discovery of the recurrent laryngeal nerve. He tells³⁴ how a surgeon, excising a tumour of the neck, cut too deep and rendered his patient half dumb. Galen was able to reproduce the situation experimentally in a living pig; by tracing the nerve from the brain to the vocal organs he showed its structure as an organ of voluntary motion. By gently squeezing the nerve of *both* sides he was able to deny the pig its voice for as long as he pleased and then to permit its recovery.³⁵ His experimental analysis extended to the control of all thoracic motions.³⁶

In tracing out the anatomy of the recurrent laryngeal nerve Galen was struck by the fact that it descends to the thorax and folds itself over thoracic structures before ascending again to its proper destination in the throat. His answer lay in the general principle that nerves, being soft, were always inserted into the end of the muscle that moved the least, in order to avoid damage. The top of the vocal organs was more mobile than the bottom, and therefore the nerve had to approach it from below: but a long, soft nerve needed support over such a distance, and so nature contrived to support it upon the thoracic arteries.

Another experiment of Galen's,³⁷ as striking as that upon the recurrent laryngeal nerve, was the serial section of the spinal cord. Again, the living pig was secured to the operating table and a scalpel was inserted between each vertebra to destroy the longitudinal fibres. Beginning above the sacrum,³⁸ Galen repeated the operation at every vertebra and carefully noted the results. In this way he was able to establish the distribution of the spinal nerves and the manner of their control of the organs: he noted the progressive loss of sense and motion as the operation proceeded through the thoracic vertebrae into the cervical. In particular, he was able to isolate the nervous control of the various parts of the motions of respiration, making the animal breathe by the intercostal muscles or by the diaphragm alone. In these experiments Galen exhibited an acute power of

observation, and his anatomy is very detailed.⁴⁰ He described the *rami communicantes*⁴¹ of the spinal nerves but did not discover the sensory and motor function of the different nerve roots.

In exploring the nerves of the thorax Galen paid some attention to the vagus and sympathetic trunk on their journey through the chest. He did not always clearly distinguish between the two nerves, sometimes describing the sympathetic trunk as a branch of the vagus, and always regarding it as a cranial nerve, the sixth of the seven pairs of the enumeration he adopted from his teacher, Marinos. The earliest account he gives of the sixth pair is in *On the Use of the Parts*,⁴² and it is largely based on the nervous anatomy of domestic animals. Consequently, the nerve he describes is single down to the level of the top of the thorax, the common vagosympathetic trunk of a number of animals including the horse and the pig.⁴³ The purpose of both nerves for Galen was to give sense and motion to the abdominal viscera and lower organs; accordingly, both nerves were obliged to travel over a great distance from the head, and as it was in the nature of a nerve to be soft, they had to be defended against damage on their journey. This is the reason, says Galen, for the plexuses and ganglia he saw on the sixth pair, and for the attachment of the sympathetic trunk to the spinal nerves 'at the roots of the ribs'.

This account of the thoracic parts of the sixth pair shaped all anatomical opinion until, and after, Vesalius. It became formalised in the statement that the sixth pair descended to the level of the first rib and divided into three branches, the 'stomachic' (the vagus), the recurrent laryngeal, and the 'costal' (the sympathetic). The costal was so called because of its connection with the spinal nerves to the muscles of the ribs, the intercostals. Later the 'costal' for the same reason became known as the 'intercostal', which led in the 17th century to confusion with the true intercostal nerves that Galen had described adequately. In the later *On Anatomical Procedures*, based on apes, Galen has a much clearer picture of the separate paths of the vagus and sympathetic trunk in the neck and thorax.

We have already seen that Galen rejected the Aristotelian notion that the nerves arise from the heart. We have also seen that this may in fact be based upon something of a misunderstanding of Aristotle's position, because, in his day, nerves were not clearly distinguished from other fibres. At all events, Galen's rejection of Aristotle is part of his wider attack on the whole notion of cardiocentricity. He devoted a large part of his book on

the opinions of Plato and Hippocrates⁴⁴ to establishing the supremacy of the brain as a centre of control. So strong was the idea of nervous control of muscular motion, and so anxious was Galen to deny nerves to the heart, whether leaving it or *entering* it, that he denied that the heart was a muscle. Instead, he claimed that it moved by means of its own unique, innate Pulsific Faculty, and its motion was *natural*,⁴⁵ arising from the 'nature' of the heart, not *animal*, the motion of the skeletal muscles arising from the will (*anima* in the Latin tradition). This action of the heart was one of expansion, not contraction, so that the active phase of the heart's motion was diastole. This was the basis of his analogy with the blacksmith's bellows, which were forcibly opened by the smith, drawing in air through the same nozzle that also fed the fire: the heart *drew in* blood from the vena cava, and, in turn, the actively expanding arteries drew in the heart's blood with a pulse derived from the heart.

Here Galen is consciously disagreeing with Alexandrian opinion, which said that the heart contracted forcibly, expressing its contents. His opinion, however, agrees with a wider notion in his physiology: voluntary muscles were composed only of longitudinal fibres which contracted, physically pulling the tendons and bones, but the hollow organs of the viscera⁴⁶ were composed of three different kinds of fibre, and acted by means of Faculties that were essentially biological and not physical. Each hollow organ was composed of longitudinal or straight fibres, which exercised a Faculty of Attraction, circular fibres that enabled the Expulsive Faculty to eject the contents of the organ, and transverse fibres, which, in a concerted action with the other two, retained the contents.⁴⁷ All these Faculties were subdivisions of the Nutritive Faculty and were primarily exercised in the organs of nutrition. Although the left ventricle was the home of the Vital Faculty, the right ventricle was part of the venous-nutritive system that Galen said was controlled by 'nature'. In saying that the motions of the whole heart and the arteries were 'natural', Galen meant that they were not controlled by the rational soul or the psychic faculty in the brain.

THE MOVEMENT OF THE HEART AND BLOOD IN THE FETUS

Apart from the invisibly small septal pores, Galen's description of the anatomy of the heart was precise. He knew of the fetal ductus arteriosus and the foramen ovale and their fate at birth. Yet his physiology of fetal bloodflow contained three major errors in modern terms: he imagined that

in both adult and fetus blood crossed the septum, that the flow of blood in the veins in the bulk of the body was centrifugal, not *to* the heart as in modern physiology, and, lastly, in specific reference to the fetal condition he imagined that maternal blood crossed the placenta to supply the fetus. Even with these constraints upon his interpretation of fetal bloodflow Galen was able to explain in a way that fitted admirably with the rest of his physiology how the particular needs of the fetus were met. The fetal lungs, deprived of air, had no need of an adult vascular supply, and the needs of the fetus were met by the maternal blood, which completely bypassed the fetal heart, the action of which was unnecessary in the fetus; it beat but did not expel its contents.⁴⁸

Galen assumed that the maternal venous blood, flowing through the umbilical vein, reached the fetal liver and rose to the heart through the vena cava in the usual way, from A to C (Fig. 1). Since the fetal lung was not functioning, Galen supposed that there was no need for the right ventricle to exercise its only function, that of preparing blood for the lung. The blood consequently did not enter the right ventricle but passed directly through the open foramen ovale (obscured in the diagram by the vessels) into the left auricle (H, Fig. 1). Since Galen considered the auricles simply as sinewy expansions of the vessels, the blood in this transit did not pass through the heart at all but ascended from the left auricle to the lung through the venous artery (G, Fig. 1), which not only looked like a vein but also in the fetus carried venous blood.

Maternal arterial blood, said Galen, entered along the route umbilical arteries—fetal iliac arteries—fetal aorta. From the aorta it was distributed to the body in the usual way, with the exception of the lungs. Since the fetus was not respiring, the whole lungs—heart—arteries respiratory system of the adult was fed from the lower end, and its functional direction was reversed in the fetus. Approaching the heart in the aorta at I (Fig. 1), the maternal arterial blood had no need to enter the fetal heart, the left ventricle of which was not engaged in the production of spirit; in any case, the aortic valve would have prevented any substantial flow. The only route for the arterial blood to reach and vivify the lung was across the fetal ductus arteriosus J (Fig. 1) and up the arterial vein, which consequently in the fetus not only looked like an artery but carried arterial blood. At birth the umbilical bloodflow stopped, air entered the lungs, and the foramen ovale and ductus arteriosus closed, producing a normal adult Galenic bloodflow.

Conclusion

Galen stands at a critical point in the development of biological science. The Hellenistic descriptive and experimental tradition was summarised and extended in his description of the morphology of the heart and the changes occurring in the fetal heart at birth, which is accurate enough by modern standards. In that sense Galen's account of the heart looks forward to modern medicine. Yet his account of the functioning of the adult heart was almost entirely dominated by traditional ideas, which we met in the first article. In other words, Galen did not derive his ideas on function from those on structure; nor, indeed, did any other student of the human body, for almost invariably in the history of anatomy and physiology ideas of function have either instituted or modified anatomical statements. For example, Galen's description of the interventricular cardiac pores is matched by his account of an anatomical pathway from the nose to the ventricles of the brain, and for the escape, in the reverse direction, of the waste products of the concoction of animal spirits.⁴⁸

This problem of the relationship between form and function is highlighted by the case of the heart, which is a complex structure. Indeed, the mammalian heart is *unnecessarily* complex and arose as a four-chambered organ with a 'figure of eight' circulation from the evolutionary accident that the primordial lungs that were to take over the function of the ancient gills, as the ancestor of air-breathing animals moved out of the sea, already had their own blood supply with a venous return direct to the heart. This venous blood came to be arterial and in order to provide efficient circulation, should have gone directly to the body, but the existing pathways could not be abandoned, so the arterial blood returned to the heart to be sent out again. The four chambers of the heart evolved as a complex device to handle the double circulation. Further, the major changes taking place in the chambers, vessels, and fluids of the fetal heart at birth are an additional complexity also due to the secondary development of air-breathing in evolutionary history. They are necessary to adapt the already secondarily complex four-chambered heart from an aqueous to gaseous environment.

It would not be difficult for a hydraulic engineer to design a simpler and more efficient organ and circuit of circulation, and it is no surprise that Galen's interpretation of the structure does not match the modern account. His interpretation is a very good example, because of the complexity

of the appearances, of the nature of his biological interpretation as a whole, which has two aspects. Firstly, Galen discussed scientific procedure in making discoveries but, secondly, he knew in advance what *kind* of thing he was going to discover. He wrote a book on scientific method, of which he was proud and which has been lost. It seems to have included discussion on inductive generalisations from sense experience, and also much on *deductive* reasoning, on the pattern of geometry, from certain irrefutable axioms. Whenever we read about 'reason' in old texts on anatomy and physiology we may be sure it is axiomatic, deductive reasoning that is being referred to. These axioms reveal a great deal about the world-picture of the writer; they are the ideas from which his reasoning *started* and were themselves incapable of proof or rejection by reason. Broadly, they represent the *kind* of thing Galen knew he was going to find by applying the Aristotelian inductive or the Alexandrian experimental method. (Galen's experimental method was not entirely modern. Most often his experiments are designed to prove someone else's ideas wrong; and so are part of a general mode of proof by rejecting all known alternatives. He does not use experiment to 'see what happens' or to establish his own uncontested ideas. An excellent possibility here would have been to inject water into the right ventricle to demonstrate the pores of the septum.)

So, in purely medical topics, Galen uses the axioms of contraries-cure-contraries as the basis of his therapeutics so that medicines with the fundamental Elemental Qualities of Wet and Cool are used in Hot and Dry diseases. In anatomy and physiology, Galen's most fundamental conception was that of Nature as the Creator of the body. Unlike the Christian conception of a Creator, Galen's Nature was not omnipotent and had certain recognisable characteristics. She was bound by the Necessity, such as the nature of the materials she was working with, she was endued with Reason, handling the Qualities of the materials in the best possible way, and she was beneficent, always bearing in mind the well-being of the animal and of the species. Being reasonable, Nature never duplicated her efforts by doing something unnecessarily; 'Nature does nothing in vain' is Galen's most frequent axiom in reasoning about the structures of the body and their function. That the structure of the heart was *unnecessarily* complex, that some mindless process of evolution had caught up the chambers and vessels of the heart in an irreversible complexity, and that any competent engineer could do better, would all have been entirely foreign to Galen's way of

thinking. His knowledge of comparative anatomy told him that animals without lungs did not have a right ventricle, but these animals were 'imperfect', not merely simpler. His knowledge of animal form also told him that there was a single Mind that fashioned all of nature. The guiding principle behind all his anatomical and physiological research was to discover the rationality of Nature.

Lastly, let us see how this principle worked in Galen's analysis of the thoracic organs. He saw the invisibly small septal pores of the heart with 'the eye of reason', arguing that the clearly visible but apparently blind pits on the wall of the right ventricle *must* in fact perforate into the left ventricle, otherwise the pits would be without function; but Nature does nothing in vain, and nothing in the body is without function, therefore the pits are perforate. We have already seen that Galen's physiological theory dictated that nerves entered the least-moving end of a muscle, and so the recurrent laryngeal nerve had to descend to the thorax in order to approach the vocal organ from below. But one of the Necessities that Nature labours under is that nerves are soft even though they have to be stretched over long distances. As we have seen, such nerves as the vagus and sympathetic trunk were consequently equipped by Nature with ganglia and plexuses to hold them steady on their course, and the recurrent laryngeal was supported by Nature with the aorta on one side and the subclavian artery on the other (as an inferior substitute).

Galen is very clear about the roles of Reason and Necessity in the creation of the pulmonary vessels. Nature's reason in creating them was to take air to the heart and blood to the lung; the Necessity that constrained Nature was the elementary qualities of Moist and Dry, which Nature blended together to produce a plastic, waxy substance. Drying out some parts with the Hot and stiffening others with the Cold, Nature formed the rudiments of the vessels.⁵⁰ Galen identified five causes in all such changes: the material, from which the organ was made; the efficient, the immediate instrument (Hot and Cold); the formal, or shape of the product; the final, the purpose of the whole operation; and, lastly, the Creator or Nature herself. Within this philosophical framework Galen had to explain the anomalous structure of the pulmonary vessels. We may refer to the account of these vessels given above and recall the Final Cause, Nature's reason, the exchange of fluids; the Material Cause, the constituent material, with the added Necessity of the vein being thick-walled to retain its fine blood and the artery being thin-walled to aid the expulsion of its

contents (part of the Formal Cause); and the Efficient Cause just mentioned, Hot and Cold. With this framework Galen must have been confident of his position, and he could afford to be scathing about those who attempted to explain the anomaly of the pulmonary vessels without Reason, Necessity, or Causality. Thus he attacks, with his customary gusto, the opinions of Asclepiades, who had argued that the venous arteries of the lung (the pulmonary veins) were thin-walled because they worked twice as hard as other arteries in having a double motion—one from the lungs in respiration and another from the pulse. The arteries in the rest of the body, on the other hand, move moderately with their own motion and so grow well-nourished and strong. The veins in the body as a whole, continued Asclepiades, do not move and so waste away like a lazy slave who takes no exercise, but the arterial vein of the lung does move, and so grows strong.⁵¹ However much Galen's teleology disagrees with modern evolutionary theory, it is clear that he was philosophically much better equipped than some of his immediate predecessors.

Another form of Necessity constraining Nature in constructing the body in Galen's system was the opposing Qualities of neighbouring parts. In general, a hard part had to be separated from a soft, lest it damage it, by a third part of middling softness. Thus the comparatively soft and very noble heart would be damaged by its proximity to the sternum, were it not for the pericardium, a membrane of intermediate nature.⁵² 'Nobility' was also a concept that played a part in Nature's reason, the more noble organs being those that housed the higher faculties. They were consequently given precedence in position in the body, organs of less importance being displaced from their own ideal position.

Notes and references

- 1 Edelstein, L. *Ancient Medicine*, Baltimore, 1967: The history of anatomy in antiquity, pp. 247–301.
- 2 Galen, *Anatomical Procedures*, trans. Singer (cf. note 3), p. 31.
- 3 Galen tells us about Diocles' text in *On Anatomical Procedures*, trans. Singer, C., Oxford University Press, 1956, p. 32. For the dating and fragments of Diocles, see Jaeger, W., *Diokles von Karystos*, Berlin, 1938, summarised in English in *The Philosophical Review*, 49(1940), 393–414.
- 4 The evidence for human dissection by the Alexandrians has been disputed. The most important source is Celsus—in the proemium to his *De Medicina* (there is a translation by W. G. Spencer in the Loeb series, London, 1935)—who is probably

the source of many later comments, such as those of Tertullian, who called Herophilus a butcher who cut up 600 people (see the tenth chapter of *De Anima* in the edition of J. H. Waszink, Amsterdam, 1947, p. 13). Tertullian, however, also depends in part upon Soranus, an opponent of dissection and a possible source of antivivisection opinion. The whole question may have come into prominence as a result of its adoption as a topic in rhetoric. Another classical source is Rufus of Ephesus (it has been translated by A. J. Brock in his *Greek Medicine*, London, 1929, p. 126), and these accusations were repeated in the middle ages by St. Augustine and Vindicianus. The pseudo- (and post-) Galenic *Finitiones Medicae* speaks of the Rationalists' advocacy of vivisection as if the debate were still a live issue. Later medieval sources report that the Alexandrians vivisected first the nervous system, then the organs of respiration, including the heart, and lastly the organs of nutrition. This reflects the philosophical precedence of the nobility of the different organs, and so may be a medieval rationalisation of the classical practice, but it is also the most profitable sequence in which to employ vivisection, leaving until last those organs that continue to function the longest.

⁵ Strictly, the Empirical sect best known to later historians and to Galen was founded by Philinus of Cos, a pupil of the major Alexandrian figure Herophilus, but empirical attitudes were certainly debated during the period of the formation of the Alexandrian school, and the later empiricists consciously compared their ideas with the empirical Hippocratic writings.

⁶ See Jaegar, W., *Aristotle. Fundamentals of the History of his Development*, trans. by R. Robinson, Oxford, 1948.

⁷ Steckerl, F., *The Fragments of Praxagoras of Cos and his School*, Leiden, 1958, p. 34.

⁸ Lloyd, G. E. R., *Aristotle: the Growth and Structure of his Thought*, Cambridge, 1968, p. 72.

⁹ On the use of the technique in teaching see Kudlien, F., 'Medical education in classical antiquity' in *The History of Medical Education*, ed. C. D. O'Malley, University of California Press, 1970, p. 11.

¹⁰ See Matter, M. J., *Histoire de l'Ecole d'Alexandrie*, Paris, 1844, vol. 3.

¹¹ Largely reported by Galen. They have been collected by Dobson, who sometimes includes too much of the Galenic context. Dobson, J., 'Herophilus of Alexandria', *Proc. Roy. Soc. Med.*, **18** (1924-5), Sect. Hist. Med., 19-32; Dobson, J., 'Erasistratus', *Proc. Roy. Soc. Med.*, **20**(1927), Sect. Hist. Med., 21-28. See also Jones, W. H. S. *The Medical Writings of Anonymus Londinens*, Cambridge, 1947, which contains a useful discussion of the physiology of the two Alexandrians.

¹² The passage from Chalcidius is given in Diels, H., *Die Fragmente der Vorsokratiker*, Berlin, 1934, 3 vols.; vol. 1, p. 212. In this passage Alcmaeon,

Callisthenes, and Herophilus are jointly credited with discovering a number of things about the eye, including the technique of excising it and the arrangement of the optic nerves. Comparison of this passage with that of earlier editions, such as that of Meursius (I. Meursius, *Chalcidii V.C. Timaeus de Platonis translatus*, Leiden, 1617, p. 230), suggests that it cannot be interpreted to show that Alcmaeon removed the eye and dissected out the optic nerves; it is very likely that Alcmaeon is included in this list of authors on the basis of his excision of the eye. Chalcidius' description of the optic nerves agrees with what Galen tells us of Herophilus' knowledge of them, and it is very likely that Chalcidius' description of the optic nerves derives from Herophilus. Chalcidius' account, however, includes a description of the junction of the optic nerves, which thus appears to be a discovery of Herophilus, not mentioned by Galen and previously unknown to historians. (On the possibility of Alcmaeon performing dissections, see Lloyd, G. E. R., 'Alcmaeon and the early history of dissection', *Sudhoffs Archiv*, **59**(1975), 113-147; Galen's description of Herophilus' account of the optic nerves is in the edition of the *Opera Omnia* edited by Kühn, Leipzig, 22 vols; vol. 3, p. 812).

¹³ Rufus of Ephesus, *De Apellationibus Partium Corporis Humani*, in Estienne, H., *Medicae Artis Principes*, Paris, 1567, vol. 1.

¹⁴ Ed. Kühn, vol. 5, p. 549.

¹⁵ Galen, ed. Kühn, vol. 4, p. 731.

¹⁶ Galen, ed. Kühn, vol. 8, p. 703.

¹⁷ See Lonie, I., 'Erasistratus, the Erasistrateans, and Aristotle', *Bull. Hist. Med.*, **38**(1964), 426-443.

¹⁸ Galen, ed. Kühn, vol. 4, p. 706.

¹⁹ Wilson, L., 'Erasistratus, Galen and the pneuma', *Bull. Hist. Med.*, **33**(1959), 293-314.

²⁰ Galen, ed. Kühn, vol. 5, p. 185.

²¹ Good general accounts of Galen and his work are Temkin, O., *Galenism*, Cornell University Press, 1974, and Sarton, G., *Galen of Pergamon*, Kansas University Press, 1954. More specialised accounts are those of Walsh, J., 'Galen's studies at the Alexandrian school', *Ann. Med. Hist.*, **9**(1927), 132-143; Prendergast, J., 'The background of Galen's life and activities, and its influence on his achievements', *Proc. Roy. Soc. Med.*, **23**(1930), Sect. Hist. Med., 1131-1148; Harris, C., *The Heart and Vascular System in Ancient Greek Medicine*, Oxford, 1973; and Hall, A. R., 'Studies in the history of the cardiovascular system', *Bull. Hist. Med.*, **34**(1960), 391-413. A great deal of Galen's system of medicine and physiology has been covered in a number of volumes by R. Siegel, who is perhaps too inclined to interpret Galen in modern terms. (*Galen's System of Physiology and Medicine*, Basel, 1968; *Galen on Sense Perception*, Basel, 1970).

²² Rufus of Ephesus, *The Names of the Parts of the Human Body*, the relevant part of which is included in English translation in Brock, A. J., *Greek Medicine*, London, 1929, p. 126. See also Darem-

- berg's edition of 1879, p. 149, and the renaissance Latin version of Estienne (cf. note 13).
- ²³ The *Introductio seu Medicus* and the *Finitiones Medicae*: both are included, as pseudo-Galenic, in the Venice, 1625 (Junta) edition of the *Opera Omnia* of Galen in the class 'Isogogici Libri'.
- ²⁴ Prendergast, *loc. cit.*
- ²⁵ Galen, *On Anatomical Procedures*, trans. C. Singer, p. 3.
- ²⁶ Galen's most important surviving anatomical and physiological works are *On Anatomical Procedures*, the first half of which survives in Greek and has been translated by Singer (cf. note 3) and the second half of which survived only in Arabic. This is available in English translation (by W. H. L. Duckworth), Cambridge, 1962. *On the Use of the Parts of the Body* is Galen's major philosophical and functional interpretation of structure; see the translation by M. T. May, *Galen on the Usefulness of the Parts of the Body*, Cornell University Press, 1968 (2 vols). These two Galenic texts contain the fundamentals of his thoracic anatomy and physiology, including experimental vivisection of the nerves. The biological powers that are the fundamental principles of his physiology are discussed by Galen in *On the Natural Faculties*, which has been translated by A. J. Brock in the Loeb series, London, 1916. Galen's specialised tracts on aspects of thoracic structure and on thoracic medicine are not so well served by English translation. He wrote *On the Cause of Respiration* (Kühn's ed., vol. 4, pp. 465-469), *On Difficulty of Respiration* in three books (Kühn, vol. 7, pp. 753-960), and *On the Use of Respiration* (Kühn, vol. 4, pp. 470-511).
- ²⁷ Kühn's ed., vol. 5, p. 525.
- ²⁸ Galen discusses the opinions of Hippocrates and Plato in *De Hippocratis et Platonis Dogmatibus*: Kühn's ed., vol. 5, pp. 520-538.
- ²⁹ On many occasions Galen presents animal anatomy as if he were discussing the human body, and, in particular, *On the Use of the Parts* is based on the structure of the domestic animals (with some simian material). The book is addressed equally to philosophers and to physicians, and Galen is anxious throughout to illustrate the virtues of Nature as a Creator: the human body in this connection is obviously of much greater interest than that of animals, and Galen slides easily from one to the other without always keeping his readers fully informed. (In contrast, the strictly practical *On Anatomical Procedures* is expressly about the dissection of apes.) A good example of Galen misleading his audience is his discussion of the lung: 'It is not my purpose to speak of the number of lobes in each of the other animals, nor is my discourse ever concerned with the construction of any other instrument in animals, except perhaps to provide a point of departure for the explanation of it in man. If death does not come to me soon, I shall one day explain construction in animals too, dissecting them in detail, just as I am doing for man'. (May's translation of *On the Use of Parts*, p. 285). However, Galen describes a non-respiratory 'fifth lobe' of the lung, constructed solely, he says, to support the vena cava in its passage through the thorax; this lobe is a simian feature, illustrated in Singer's translation of the first half of *On Anatomical Procedures* (p. 273).
- ³⁰ *An in arteriis sanguis contineatur.*
- ³¹ See Harris (note 21) p. 268.
- ³² Harvey, W., *The Circulation of the Blood*, trans. K. J. Franklin (Everyman ed.), London, 1963, p. 17.
- ³³ Kühn's ed., vol. 8, p. 58.
- ³⁴ Kühn's ed. vol. 8, p. 55; Duckworth's translation of *On Anatomical Procedures*, p. 76. See also Walsh, J., 'Galen's discovery and promulgation of the function of the recurrent laryngeal nerve'. *Ann. Med. Hist.*, 8(1926), 176-184.
- ³⁵ Duckworth's translation of *On Anatomical Procedures*, pp. 91, 106, 107, 210.
- ³⁶ Book 8, Chapter 5 of *On Anatomical Procedures*: Singer's translation, p. 211.
- ³⁷ Galen seems to have enjoyed working before an audience, and no doubt appreciated their reaction to the spectacle of a secured and noisy pig being dramatically silenced. He tells us how he was asked to perform the experiment before a group: Kühn's ed. vol. 14, p. 626.
- ³⁸ Duckworth's translation of *On Anatomical Procedures*, pp. 20-24.
- ³⁹ Singer's translation of *On Anatomical Procedures*, pp. 211ff.
- ⁴⁰ His material for these experiments was the Barbary ape, and until very recently it has been impossible to confirm just how precise his anatomy was because of the modern rarity of this species. The American anatomist, C. M. Goss, has recently been able to follow Galen's dissections on an embalmed specimen from their limited range on the Rock of Gibraltar ('where they are held sacred by the British' in Goss's words) and has been able to establish the great accuracy of Galen's descriptions (private communication).
- ⁴¹ French, R. K., 'The origins of the sympathetic nervous system from Vesalius to Riolan', *Med. Hist.*, 15(1971), 45-54.
- ⁴² May's translation, pp. 445ff.
- ⁴³ Sisson, S., *The Anatomy of the Domestic Animals*, Philadelphia, 1953, pp. 852, 878.
- ⁴⁴ *De Hippocratis et Platonis Dogmatibus*: Kühn's ed., vol. 5.
- ⁴⁵ *De Motu Musculorum*: Kühn's ed., vol. 1, p. 1.
- ⁴⁶ Kühn's ed., vol. 1, p. 602.
- ⁴⁷ May's translation of *On the Use of Parts*, p. 294.
- ⁴⁸ Harris, *op. cit.*, pp. 290ff.
- ⁴⁹ May's translation of *On the Use of the Parts*, pp. 41, 425.
- ⁵⁰ *Ibid.*, p. 311.
- ⁵¹ *Ibid.*, p. 309.
- ⁵² *Ibid.*, p. 320.

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