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CHAPTER IV

The Study of Man

A new understanding of the human body in the Renaissance resulted from anatomical studies pursued with an intensity probably unequaled at any time earlier. Here we may follow a series of Paduan professors and their students: Andreas Vesalius, Realdo Columbo (c. 1510–1559), Gabriele Falloppio (1523–1562), Hieronymus Fabricius of Aquapendente (c. 1533–1619), and William Harvey. But the period between the publication of the *De fabrica* (1543) of Vesalius and the *De motu cordis* (1628) of Harvey also witnessed the contribution of others whose work does not always fit so neatly into the pattern of modern science. Thus, Michael Servetus (c. 1511–1553) described the pulmonary transit of the blood in a theological tract (1553), and we shall find that the analogy and interrelation of the macrocosm and the microcosm reappears here again as a stimulus for both research and speculation. Perhaps nothing is more revealing of the complexity of early-seventeenth-century intellectual currents than the fact that most of the main figures of this story openly professed their allegiance to Aristotle and Galen whereas the English alchemist-physician Robert Fludd was the first to support the Harveyan circulation in print (1629) because of what seemed to him to be its deep mystical connotation.

The Medieval Heritage

As in all other fields of science, the anatomy and physiology of the Renaissance was based initially upon texts and concepts that had survived from earlier periods. In part this meant an acceptance of the macrocosm–microcosm analogy as understood by Aristotle and it also meant a vitalistic view of nature – one that would become the object of attack by seventeenth-century mechanists.

But in addition to the survival of ancient philosophical concepts, there was also an imposing body of anatomical and physiological information that had come down from antiquity. Both Alcmaeon of Croton (c. 500 B.C.) and Aristotle (384–322 B.C.) had been interested in the description of the parts of men and animals, and in Alexandria Herophilus and Erasistratus (fl. 280 B.C.) presided over a flourishing school of anatomy. Later it was said that they had made their observations through the vivisection of criminals furnished to them by the Ptolemies, but whether or not this is true, there is little question that the Alexandrian anatomists did dissect human cadavers. The results were to be seen in detailed anatomical descriptions of the parts of the human body and their comparison with the similar parts of animals. In addition, their physiological investigations were to be the subject of discussion for nearly two thousand years.

If the Alexandrian anatomical studies remain a high point of ancient science, their full texts were lost in succeeding centuries as a result of the overwhelming influence of Galen. Originally a surgeon to the gladiators in his native city, Pergamum, Galen traveled widely throughout the empire and was to write on all aspects of philosophy and medicine. It was his work rather than that of his predecessors that was to be abstracted and digested by the medical authors of late antiquity and Islam. And it was the continued influence of his work that Paracelsus and his chemical followers reacted against in the sixteenth century. It would be hopeless to try to summarize the extensive writings of Galen, but it is necessary to note a few points that proved particularly vexing to sixteenth-century anatomists.

Galen's anatomical and physiological works were both lengthy and detailed. His work is of particular importance for his examination of the spinal cord, the mechanism of breathing, and the cardiovascular system. But his conclusions were based only to a small degree upon human dissection. He relied most upon animals that were easily available: that is, sheep, oxen, pigs, dogs, and especially the Barbary ape. It is not surprising, then, that he should have made some notable errors. A five-lobed liver (based upon the dissection of a dog) and the *rete mirabile* (an elaborate network of blood vessels not present in man) were described as part of human anatomy. These errors and others were to remain part of anatomical teaching until the sixteenth century.

Of special significance was Galen's description of the cardiovascular system (Figure 4.1). Here the discovery of fundamental errors in his texts during the Renaissance was to lead to a radically new concept of the blood flow. For Galen the blood originated in the liver and from there proceeded to all parts of the body through the veins. Rich in natural spirits, this ve-

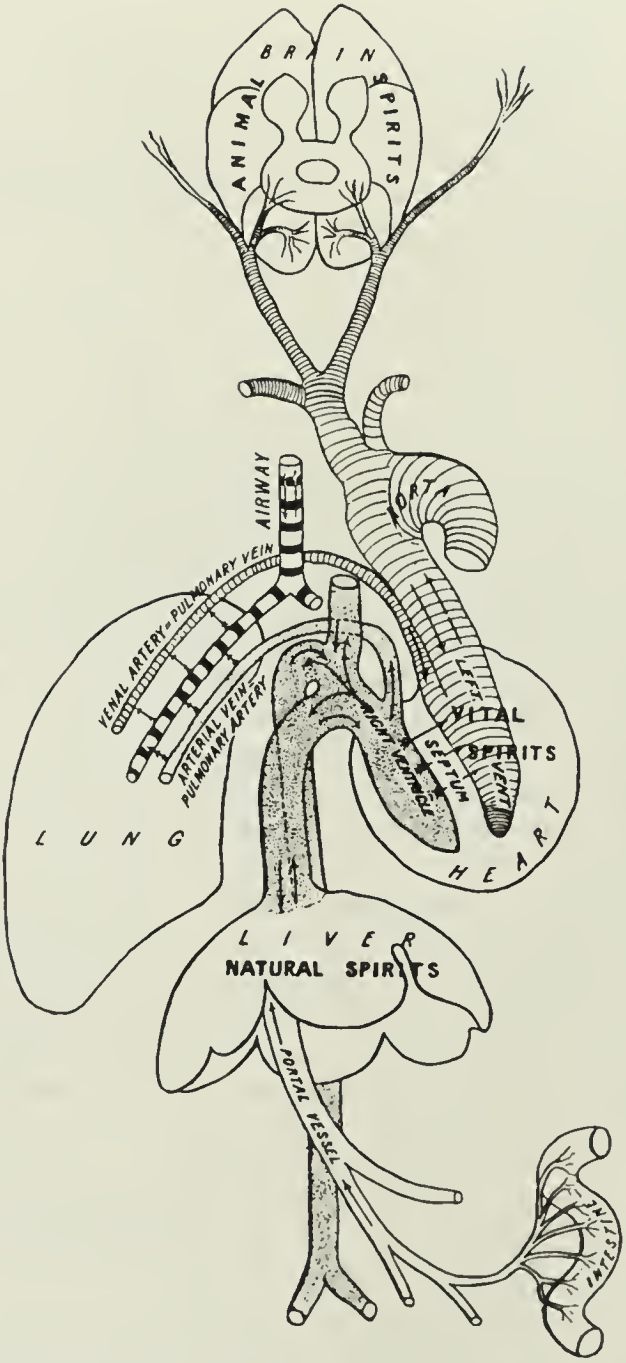

Figure 4.1. Diagram of Galen's physiological system. From Charles Singer, *The Discovery of the Circulation of the Blood* (London: Wm. Dawson and Sons, Ltd., 1956). Courtesy Mr. A. W. Singer.

nous blood had the function of nourishing the body tissues and at the same time carrying away waste substances. Eventually this spent venous blood reached the right ventricle of the heart. Most of it was routed first to the lungs and then to the liver after having been purged of accumulated impurities. However, Galen postulated the existence of pores between the right and left ventricles of the heart through which a very small portion of the venous blood moved to the left cavity. This portion was there combined with air from the lungs to form the vital spirits required for life and these were then distributed through the arteries. A final transformation occurred in the brain, where animal spirits were prepared and routed through the nerves. The key to this system rested in the interventricular pores, openings that do not exist. When this was discovered a rethinking of the entire system was necessary.

But the revision of Galenic physiology was not to take place for more than a millennium. This was due partially to the fact that Galen was the last great figure of Greek anatomy and physiology. But it was due also to the fact that later ancient physicians applied themselves less to new research than to the abridgment and codification of Galen's writings. And if Islamic medicine was later to be strongly influenced by Galen, the emphasis of the Arabic texts was directed more toward the cause and cure of disease than to anatomy and physiology. The learned world of the West was first to reflect the Eastern texts from translations made in the thirteenth century. And because of these Islamic interests, Western scholars of the Middle Ages knew relatively little of the anatomical works of Galen. Only the lesser work *On the Functions of the Members* and a severely abridged version of *On the Use of the Parts* were readily available to thirteenth-century physicians.

In contrast to the limited number of anatomical texts available, a good omen for the future was to be found in the early revival of public dissections. Animals were examined once more at Salerno in the thirteenth century, and early in the fourteenth century Bologna became the center for anatomical studies. Here the stimulus originated not from the medical faculty, but from the law school, whose members saw the need for postmortem examinations. The anatomical text prepared there by Mondino de' Luzzi (c. 1275–1326) in 1316 was to become the standard for public dissections until well into the sixteenth century (Figure 4.2). In it Mondino proceeded to describe first the organs of the abdominal cavity and then worked outward to the head and the extremities. This order gave first attention to those parts most likely to decay, a subject of great importance in a period that lacked adequate preservatives.

Medieval medical schools were quick to recognize the significance of

Figure 4.2. A medieval anatomy scene. The physician-lecturer expounds the text – most likely Mondino – while the barber-surgeon dissects the cadaver. From the *Fasciculo de Medicina* (1493), as reproduced in *Medical World News* (12 January 1976).

such demonstrations, and it soon became mandatory for medical students to attend a specified number of public anatomies. By 1400 the public anatomy had become a standard part of the curriculum at most universities. Yet it must be stressed that these were demonstrations meant to acquaint students with the parts of the body; they made no pretense of being new research.

An Anatomical Renaissance

The persistence of tradition ensured the publication of Mondino's anatomy in the late fifteenth century, but the medical humanism of the period placed a new stress on the texts of antiquity. It was soon recognized that the most important anatomical works of Galen had not been available to scholars, and a determined effort was soon underway to prepare them for publication both in Greek and Latin. Galen's *On the Use of the Parts* appeared in several Latin translations by 1500, and the English medical humanist, Thomas Linacre, founder of the London College of Physicians (1518), dreamed of the publication of a complete Greek edition of Galen. He was in fact responsible for a number of editions of individual medical works, among them Galen's *On the Natural Faculties* (1523). Even more industrious was Johannes Guinter of Andernach, professor of medicine at Paris, who devoted much of his early professional life to the preparation of Greek medical texts. Not only did he translate the larger part of Galen, but he also prepared editions of a number of other physicians of late antiquity: Paul of Aegina (late seventh century), Caelius Aurelianus (seventh century), Oribasius (c. 325–c. 400), and Alexander of Tralles (sixth century). In addition, he wrote books on the plague, medical spas, obstetrics – and, in his old age, a defense of Paracelsian chemical medicines.

Of real significance is the fact that Guinter had only recently completed his translation of Galen's *On Anatomical Procedures* (1531) when a new student, Andreas Vesalius, entered the medical program at Paris. Recognizing the talent of this young man, Guinter enlisted him as an assistant in the preparation of his own text, the *Anatomical Institutions According to the Opinion of Galen for Medical Students* (1536). Although Vesalius was later to express a low opinion of his master's expertise, the fact remains that he gained from him the most advanced training in this field available anywhere in Europe – plus Guinter's strong Galenic bias.

A shrewd observer, Vesalius quickly became aware of many errors in Galen – and the need to depict the parts properly. Here his work may be seen as analogous to that of Brunfels, Bock, and Fuchs, who realized the

importance of new illustrations in the field of botany. But it would be wrong to credit Vesalius alone with modern anatomical illustration. Leonardo da Vinci's (1452–1519) earlier anatomical drawings were masterful, but unfortunately of little impact as they were unpublished. But others did anticipate Vesalius on this score, most notably Berengario da Carpi of Bologna (c. 1460–c. 1530), who had new anatomical drawings prepared for his commentary on Mondino.

The path to the *De humani corporis fabrica* was a relatively short one. Leaving Paris, Vesalius taught for a year at Louvain (1536) and then took his medical degree at Padua, where he was immediately appointed lecturer in surgery (1537). In addition to his travels and teaching Vesalius was constantly writing. In 1538 his *Tabulae sex* – six sheets of text and illustrations – appeared at the request of his anatomical students. Three of these were illustrated by Jan Stephen van Calcar (1499–c. 1550), a student of Titian. In 1541 Vesalius contributed to an edition of Galen, and two years later his masterwork on the human body was published (Figure 4.3). Shortly after its publication he was appointed physician to the emperor, Charles V, and then to his son, Philip II of Spain. A man of great energy, Vesalius was preparing to return to Padua when he died while returning from a pilgrimage to Jerusalem in 1564.

The *De fabrica* had its greatest impact because of its plates (possibly also by Jan Stephen van Calcar) (Figure 4.4). But when we turn to the text we find the expected Galenic foundation. Like other medical humanists Vesalius avidly sought minor errors in the ancient texts. This was accepted scholarship and did not affect the general esteem in which the ancient physicians were held. But Vesalius adhered to a Galenic organization as he led the reader first to the skeleton, then the muscles, the cardiovascular system, and finally the brain and the organs of the abdominal and thoracic cavities. This order is the reverse of Mondino's practical method of dissection.

Our own interest must remain centered on Vesalius's treatment of the heart and the arterial and venous systems. Here he was decidedly conservative. The Galenic spirits (natural, vital, and animal) are not questioned and there is no real departure from Galen in his discussion of the blood flow. As to the heart, Vesalius was so reluctant to reject the Galenic position regarding the interventricular pores of the septum that he wrote that

"The septum is formed from the very densest substance of the heart. It abounds on both sides with pits. Of these none, so far as the senses can perceive, penetrate from the right to the left ventricle. We wonder at the art of

Figure 4.3. The title page of the *De fabrica* (Basel, 1543). Note that it is Vesalius himself who is dissecting the body – a far different scene from the Mondino illustration of 1493. Courtesy of the Newberry Library, Chicago.

Figure 4.4. One of the plates illustrating the human muscles. From Andreas Vesalius, *De humani corporis fabrica* (Basel, 1543). Courtesy of the Newberry Library, Chicago.

the Creator which causes blood to pass from right to left ventricle through invisible pores."

Here observation is rejected in favor of authority, which affords us some insight into the authority Galen commanded in the mid-sixteenth century.

Vesalius was to publish a second edition of the *De fabrica* in 1555. Here he returned to the problem of the interventricular pores of the septum once more. But now he observed that "although sometimes these pits are conspicuous, yet none, so far as the senses can perceive, passes from right to left ventricle." Galen is now rejected, but the reader senses that it was a painful decision.

"Not long ago I would not have dared to turn aside even a hair's breadth from Galen. But it seems to me that the septum of the heart is as thick, dense and compact as the rest of the heart. I do not see, therefore, how even the smallest particle can be transferred from the right to the left ventricle through the septum."

This decision, confirmed by contemporary anatomists, was to result in a complete rethinking of the blood flow.

Vesalius himself was concerned about the criticism he received from those more conservative than he was himself: "I surely deserved something better than the slander of those who are so furiously aroused against me because their studies have not been so successful, because I don't accept Galen, and because I refuse to disbelieve my eyes and reason for his sake." Much as he revered the works of Galen himself, he rejected pointed suggestions that he publish only a work of Galenic annotations in the more traditional humanist fashion.

The Blood Flow: Vesalius to Harvey

Vesalius may not have been as much an innovator as once suggested, but there is no doubt that the *De fabrica* almost immediately became the most influential of all anatomical texts. The book and its illustrations were copied, and evidence exists to indicate its importance in a succession of master-pupil relationships that begin with Vesalius and his replacement at Padua. His successor was Realdo Columbo, who had been his assistant. He, in turn, was succeeded by Gabriele Falloppio, who is famed for his study of the human oviduct and after whom are named the Fallopian tubes. Fallopio was followed by Hieronymus Fabricius, whose work on the valves in the veins was well known to his student William Harvey. This remark-

able succession indicates the close and direct connection between Vesalius and Harvey.

The work of Vesalius had established the structure of the heart, but it surely had not settled its function. The basic physiology remained Galenic and derived from the *On the Use of the Parts.* Indeed, in regard to the heart, the lungs, and the arteries, there were few changes from Galen.

However, the followers of Vesalius almost immediately began to go beyond him in their study of the interrelation of these parts and in their study of the purpose of respiration. The first to do so was Michael Servetus, whose early training bears some similarity to that of Vesalius. True, he was to become something of an astronomer, a mathematician, and a theologian, but he was also trained as an anatomist at Paris under Guinter. Like Vesalius, Servetus was to act as Guinter's assistant. Once again we find a Galenist, which may be seen in his *Account of Syrups . . . According to the Judgment of Galen* (1536). But another early medical work attacked Leonhard Fuchs as a heretic, and there can be little doubt that Servetus was himself a religious radical in an age when it was dangerous to be a nonconformist. A Unitarian who could stomach neither Catholic nor Protestant, Servetus had published two books on the errors of the doctrine of the Trinity before the age of twenty-one. A hunted man, he assumed the name of Villanovus and took employment with a publisher. By 1546 he had written his *Restitution of Christianity,* which he sent in manuscript – along with another work on the Trinity – to John Calvin in Geneva. Now forced to flee Catholic France, he began a journey to Italy by way of Geneva. There he was recognized as the man who had attacked Calvin and was arrested while attending church. Tried for his errors, he was sentenced to death and burned at the stake with his book in 1553.

Of the thousand copies of the *Restitution of Christianity* printed in 1553 only three have survived. The book itself is an expression of Servetus's religious convictions, but it is of importance to us primarily for its fifth chapter on the Holy Spirit and the dispensation of the Divine Spirit to man. Here Servetus discussed the respiration and the relationship of spirit and air. For him the vital spirit in the body resulted from a mixture of subtle blood and inspired air – and this was not formed in the left ventricle of the heart as postulated by Galen, but rather in the lungs. Rejecting the Galenic concept of a "sweating" of blood from the right to the left ventricles, Servetus correctly described the pulmonary transit: that is, that blood from the right ventricle is pumped through the pulmonary artery to the lungs. Here a color change occurs in which the venous blood becomes lighter due to the inspired air. From there the blood travels to the left

ventricle via the pulmonary vein and is then distributed through the arterial system. It is now known that this portion of the blood flow had been correctly described by Ibn an Nafis in the thirteenth century, but there is no indication that any sixteenth-century anatomists knew his work.

It is important to insist on taking the description of Servetus in context. Here as elsewhere in this period it may be noted that significant observations occur in contexts that would be considered nonscientific today. Similar considerations regarding the aerial spirit and its relationship to the blood were to lead Robert Fludd to describe a mystical circulation of the blood just seventy years later – and were also to lead him to compose the first defense of Harvey's *De motu cordis*.

Although Servetus's views on the pulmonary transit were known a century later, it is doubtful whether the work was influential in the mid-sixteenth century. Nevertheless, there was a rapid acceptance of a nonporous septum in the last half of the century, and this fact required a new explanation of the origin of the arterial blood. Realdo Columbo reached the same result as Servetus – and probably independently – in his text on anatomy (1559). Here – in contrast to Servetus – we feel that we are in the solid tradition of Vesalian anatomy. Again we see the Galenic influence, for it is the liver that perfects the nutrient blood that is then distributed throughout the body. Similarly it is the left ventricle that distributes the vitalized blood through the aorta. However, Columbo's precise description of the heart and its valves requires the pulmonary transit for the passage from right to left. After Columbo this "lesser circulation" was generally accepted.

The final connecting link between Harvey and the school of Padua may be found in the work of Harvey's teacher in anatomy, Hieronymus Fabricius, who was associated with that university for sixty-four years. While Fabricius may be most frequently cited for his work on comparative anatomy, he is particularly important as a predecessor of Harvey for his description of the valves of the veins. His research on this subject was carried out while Harvey was a student at Padua and was published in 1603. But Fabricius, a thorough Galenist, insisted that these valves existed in order to prevent dangerous dilations. The valves acted to prevent the starvation of other parts should one locality require excess nutriment. Their absence in the arteries was explained by the normal ebb and flow of the arterial blood. For Harvey the valves were to serve as the proof of a one-way circulation of the blood.

Combined with accelerating anatomical knowledge was a new tendency at the end of the sixteenth century for some scholars to speak in general

terms of a circulation of all the blood in the body. There were a number of reasons for this. Some – like Cesalpino – were militant Aristotelians. Aristotle had spoken of the primacy of the heart in the body, and Cesalpino was to adopt the pulmonary transit as it seemed to confer greater importance to the heart. Others thought in terms of mystical celestial influences conforming to correspondences between the macrocosm and the microcosm. This accepted, it seemed only right that a microcosmic circuit should imitate the planetary (or solar) revolutions. Indeed, Roch le Baillif wrote a work on man and his "essential anatomy" that emphasized analogies between the two worlds rather than the physical anatomies of the schools. And finally there were Paracelsians who suggested that the parts of the body acted as pieces of chemical equipment. In this case it was argued that the blood circulates in the body in a manner similar to distillation "circularity." If this was all speculation, it does show the trend of the times and indicates something of the breadth of thought regarding the blood flow in the period immediately prior to Harvey.

William Harvey and the Circulation of the Blood

Like so many major figures in Renaissance science, Harvey built upon the work of his predecessors and brought together a number of seemingly disparate themes. Educated first at Cambridge, Harvey traveled to Padua in 1597 where he studied under Fabricius when that teacher was preparing his work on the valves of the veins. After taking his medical degree, Harvey returned to England in 1602 where he became a physician at St. Bartholomew's Hospital and Physician Extraordinary to James I. Elected a fellow of the Royal College of Physicians (1607), he was a member of one of the most prestigious scientific societies of Europe. He himself was to give the Lumleian Lectures there on anatomy (1615), the notes of which indicate to us his early interest in the subject of the blood flow.

Fundamental to our understanding of Harvey was his Paduan education. Because of this training, he was an admirer of both Aristotle and Galen. The extent of this may be seen in the *De motu cordis* (1628), where Harvey seems more than willing to ascribe the discovery of the pulmonary transit to Galen, and in his discussion of scientific method in the *De generatione animalium* (1651), which is based closely on the *Analytics* and *Physics* of Aristotle.

But the discovery of the circulation was based upon more than reverence for ancient genius and the belief that it was their work that should properly serve as the basis for a new scientific age. Harvey's work echoes the contem-

porary interest in new observations, in mystical analogies, and even in the use of mechanical examples.

The *De motu cordis* is a small volume, but one that displays a thorough knowledge of anatomical literature as well as Harvey's own observational evidence. Turning first to the heart itself, Harvey had examined it and the motion of the blood in some forty species. He observed that in all cases the heart hardens as it contracts and that as this contraction occurs, the arteries expand. The periodic expansions could be felt at the wrist as the pulse and he rightly assumed that this occurred because blood was being pumped into the arteries. The action of the heart then, Harvey observed, might be compared with that of a water bellows.

Referring to the hearts of cold-blooded animals because of their slower action, Harvey noted that the auricles contract first, and then the ventricles. The process is carefully described. First the blood enters the right auricle through the vena cava. As this contracts, the blood is transferred to the right ventricle, where valves make it impossible to flow backwards. The right ventricle contracts next, sending the blood through the pulmonary artery to the lungs. Again valves make it impossible to reverse direction. And, because there are no pores in the septum, all this blood is sent through the lungs. On the left side of the heart, blood from the lungs first enters the left auricle from the pulmonary vein. Then as this vessel contracts, the blood proceeds to the left ventricle. Further contraction forces the arterial blood into the aorta and the arterial system.

This was all of great interest as a physiological discovery, but Harvey now went further. Reflecting on the valves of the veins, he stated that the blood flow proceeded not only in one direction to the heart, but continuously in one direction throughout the body (Figure 4.5). At this point Harvey advanced a telling quantitative argument. Assuming that the left ventricle held only 2 ounces of blood, and that the pulse beats 72 times a minute, then in one hour the left ventricle would force into the aorta some 540 pounds of blood. At most, animals have only a few pounds of blood in their bodies and one must ask where this blood comes from – and where does it go? Harvey's conclusion is that the blood sent out from the aorta could only come from the veins:

"I began to think whether there might not be a motion, as it were, in a circle. Now this I afterwards found to be true; and I finally saw that the blood, forced by the action of the left ventricle into the arteries, was distributed to the body at large, and its several parts, in the same manner as it is sent through the lungs, impelled by the right ventricle into the pulmo-

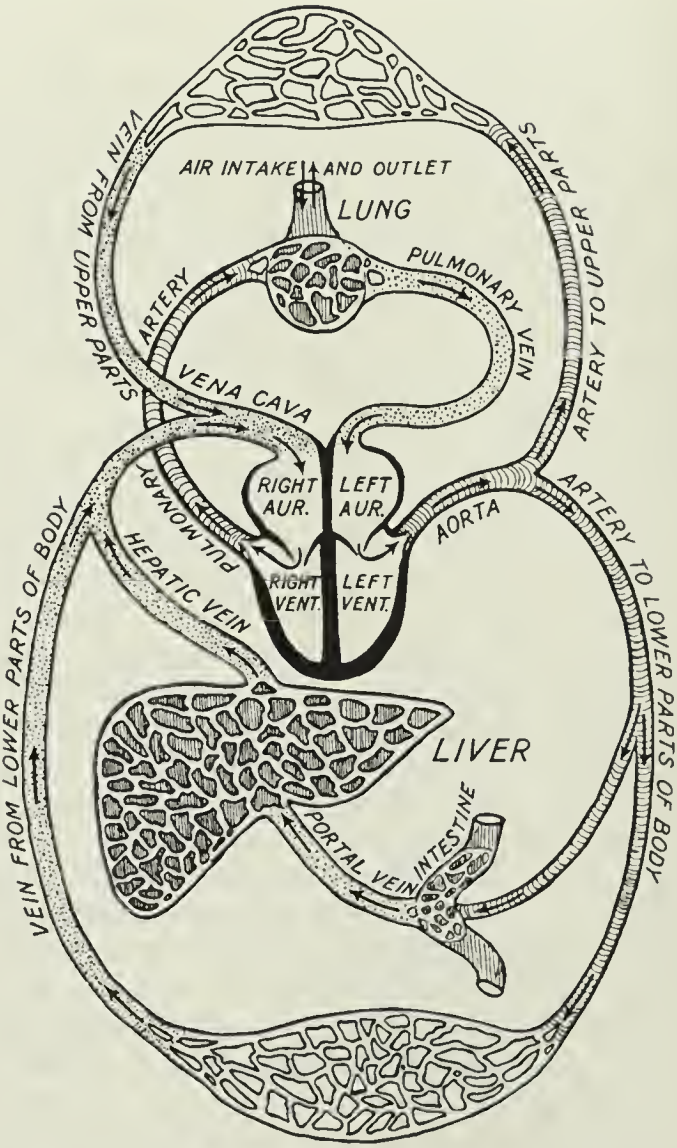

Figure 4.5. The circulation of the blood according to William Harvey. From Charles Singer, *The Discovery of the Circulation of the Blood* (London: Wm. Dawson and Sons, Ltd., 1956). Courtesy Mr. A. W. Singer.

nary artery, and that it then passed through the veins and along the vena cava, and so round to the left ventricle in the manner already indicated. Which motion we may be allowed to call circular, in the same way as Aristotle says that the air and the rain emulate the circular motion of the superior bodies; for the moist earth, warmed by the Sun, evaporates; the vapors

drawn upwards are condensed, and descending in the form of rain, moisten the earth again . . ."

The significance of the heart, evident throughout, takes on a still greater role when undertood in cosmic terms through the macrocosm–microcosm analogy:

"The heart, consequently, is the beginning of life; the sun of the microcosm, even as the sun in his turn might well be designated the heart of the world; for it is the heart by whose virtue and pulse the blood is moved, perfected, made apt to nourish, and is preserved from corruption and coagulation; it is the household divinity which, discharging its function, nourishes, cherishes, quickens the whole body, and is indeed the foundation of life, the source of all action."

Turning finally to the observations of the valves in the veins, Harvey showed that the flow of blood is always toward the heart and never away from it. His conclusion was thus well founded, for

"Since all things, both argument and ocular demonstration, show that the blood passes through the lungs and heart by the action of the [auricles and] ventricles, and is sent for distribution to all parts of the body, where it makes its way into the veins and pores of the flesh, and then flows by the veins from the circumference on every side to the centre, from the lesser to the greater veins, and is by them finally discharged into the vena cava and right auricle of the heart, and this in such a quantity or in such a flux and reflux thither by the arteries, hither by the veins, as cannot possibly be supplied by the ingesta, and is much greater than can be required for mere purposes of nutrition; it is absolutely necessary to conclude that the blood in the animal body is impelled in a circle, and is in a state of ceaseless motion; that this is the act or function which the heart performs by means of its pulse; and that it is the sole and only end of the motion and contraction of the heart."

The Verdict

Although the discovery of the circulation of the blood is today judged to be the only physiological achievement of the early seventeenth century comparable to the contemporary developments in the physical sciences, the immediate reaction to the *De motu cordis* was a mixed one. But if there were a number of conservative authors who rejected the book flatly, it is of more interest to note the spectrum of views of those who supported Harvey.

The first to defend Harvey was his friend and colleague, Robert Fludd. Long interested in an aerial life spirit and its assimilation in man's body, Fludd had described a mystical circulation of the arterial blood as a necessary consequence of the macrocosm–microcosm analogy in 1623. A witness to Harvey's anatomical demonstrations, he had arranged to have his friend's book published by his own publisher in Frankfurt. In composing his own book on the pulse (1629), Fludd spoke of his "esteemed compatriot" who had confirmed the circulation both with philosophical arguments and observational demonstrations.

But for Fludd it is evident that Harvey's anatomical evidence simply confirmed deeper mystical truths. This was understood correctly by Marin Mersenne (1588–1648) and Pierre Gassendi (1592–1655), contemporaries of Descartes and Galileo. In a detailed reply to Fludd (1631) Gassendi attacked both Fludd and Harvey on the circulation, the reason being that Gassendi professed once to have seen the presence of the pores in the septum demonstrated. And if they were there, he argued, they had to have a purpose. The proper purpose was the formation of the arterial blood, and therefore the Galenic system of the blood flow could be maintained. Not so, replied Fludd (1633); Harvey's dissections had proved to him the impermeability of the septum, and the values of the heart indicated the blood flow leading from the right to the left side of the heart through the lungs. For him the circulation was a fact, but one that could, and had been, postulated by him on the basis of cosmic truths prior to Harvey's lesser – but no less convincing – physiological evidence.

If Harvey's work could be interpreted as a proof of mystical cosmology by Fludd and attacked by mechanists for this same reason, we need not be surprised to find that René Descartes also had some reservations about Harvey's explanation. In his *Traité de l'homme* (1632) he accepted the total circulation of the blood, but only by explaining the heart in terms of a mechanical distillation unit. Assuming a higher than bodily temperature of the heart and a cooling action inherent in the lungs, he spoke of a combination of condensation and rarefaction, with the blood flow itself determined by the valves. Here Descartes attempted to convert Harvey's vitalistic system into a fully mechanical one.

Fully as interesting was the reaction of Johannes Walaeus (1604–1649), who defended the circulation and praised the genius of Harvey in two letters published in 1641. Devising a series of new experiments on dogs with vascular ligatures, he helped to extend knowledge of the blood flow. This work was of sufficient weight to influence Harvey himself. Yet the reputation of Harvey was severely damaged in the eyes of Walaeus when he was

told that the actual discoverer had been the Venetian statesman, Paolo Sarpi (1552–1623). After an extended investigation, Walaeus became convinced (1645) that Sarpi, basing his work on that of other authors going back to antiquity, had indeed discovered that circulation. Sarpi then, he wrote, had taught Harvey, who had proceeded to spread the doctrine under his own name.

In the two decades after the publication of the *De motu cordis* Harvey did suffer considerable abuse from James Primerose (d. 1659), Jean Riolan (1580–1657), Gui Patin (1601–1672), and a number of other authors, but it is also true that Harvey's work did not seem to everyone to be fully satisfactory. There still remained questions regarding the connection of the venous and the arterial systems, the different appearance of the two bloods, the role of the lungs, and the part played by the air in the formation of the arterial blood. Harvey himself had not been able to answer all these questions, but he did live long enough to receive the praise of most of his contemporaries. Shortly after his death the anastomoses between the arteries and the veins were first discovered by Marcello Malpighi (1628–1694) as he studied the blood flow in the lung of a frog with a microscope in 1659. Fourteen years later Antoni Leeuwenhoek (1632–1723) confirmed this observation with higher-powered lenses. The problem of the respiration was investigated by members of the early scientific academies, especially the Royal Society of London, and ill-fated experiments on transfusion seemed possible because of the new understanding of the blood flow. As to medical practice, the decline of the humoral theory resulted in a new interest in the chemical components of the blood. Numerous experiments were to be made in the late seventeenth century on the curing of disease through the infusion of chemicals.

But even late in the century the discovery continued to be of great interest to those who sought a mystical explanation of nature. Johann Rudolph Glauber, a late Paracelsian who contributed much to the development of large-scale chemical equipment, argued that the circulation of the blood had demonstrated conclusively the sympathetic connection of the macrocosm and the microcosm (1658). In England John Webster (1610–1682) pointed to the discovery of the mysteries of the blood made by Robert Fludd and William Harvey as subjects of importance that ought to be adopted as part of a needed curricular reform at Oxford and Cambridge (1654). And even the alchemist and early member of the Royal Society Elias Ashmole (1617–1692) referred to Harvey as a man "who deserves for his many eminent discoveries to have a statue erected rather of Gold than of marble" (1652).

The story of the discovery of the circulation of the blood may be easily cast in terms of the progressive growth of knowledge. It is possible to point to a whole series of discoveries in the period from Vesalius to Harvey. Nevertheless, these discoveries are set in a context of familiar themes. The anatomical renaissance of the sixteenth century was based upon several centuries of public anatomies at European universities. And here, as in botany, may be seen the power of the new union of art and observation. As for humanism, nowhere else was it to be more influential. The new Greek and Latin editions of Galen spurred a new interest in anatomical and physiological research. We have noted this in London with Thomas Linacre, in Paris with Guinter of Andernach, and in the whole series of Paduan teachers who were inspired by the work of the second-century Greek physician.

The new anatomy and the whole background to the discovery of the circulation is primarily associated with the University of Padua. Here there was a strong emphasis on the work of Aristotle and Galen, and we find their influence on the main figures in this development. They all approved of the correction of errors in the ancient texts, an exercise considered both right and proper, but there was no thought of overturning or replacing the ancients. Among these authorities only Guinter was to reflect favorably on the chemical remedies of the Paracelsians, but he did this without wishing to reject ancient medical theory. As for Harvey, he thought of himself as both an Aristotelian and Galenist until the end of his life.

And yet Renaissance anatomy and physiology is even more complex. When seen in context, the motives of many of these scholars differed drastically from that of modern scientists. Thus Servetus, trained as an anatomist, was prompted to set down his views on the blood flow because of his theological speculations. For Fludd the situation was similar. The understanding of nature was no less than an understanding of theology. It was on these terms that Fludd became the first to support Harvey in print. There were some who were to reject the Aristotelian Harvey because his views conflicted with the ancients whereas others were to support him, but only after stripping away the basic vitalism of his views.

In the end one is faced with the seeming paradox that one of the most impressive achievements of the Scientific Revolution was accomplished by a professed Aristotelian and that his work appealed first to mystical Hermeticists. And yet for all of this, the achievement was a great one and soon recognized as such. Others had known that the blood leaves the heart in the great arteries. But the earlier explanations had all involved a vast irrigation system with the purpose of building tissue. And if some had spoken earlier of a mystical circulation of the blood, Harvey now referred to real experi-

ments and offered an irrefutable quantitative argument. It has been suggested that Harvey's work was the first adequate explanation of a bodily process, the starting point on the road to modern physiology. Certainly there was a change in attitude toward living processes after this time. Earlier references to indefinable innate heat, pneumatic force, animal spirits, and internal *archei* were to be replaced by a new search for simpler physical conceptions.