Cambridge University Press
978-0-521-10315-2 - The Battle Against Heart Disease: A Physician Traces the History of Man's Achievements in this Field for the General Reader
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Excerpt
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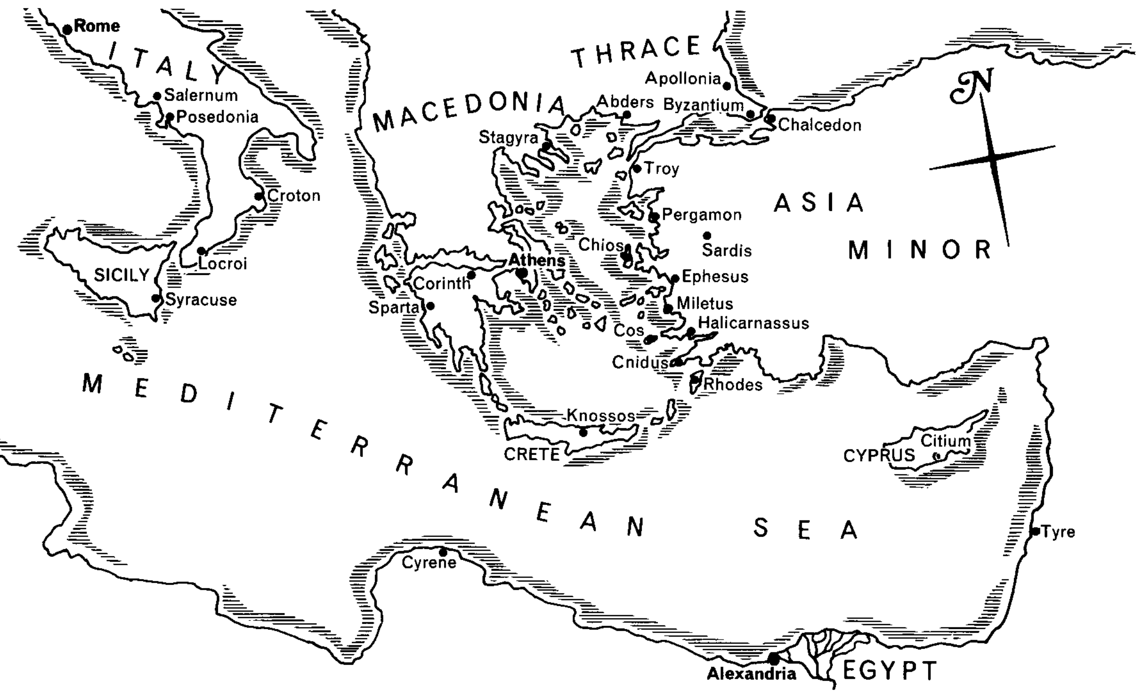
Preliminary reconnaissance by the early Greeks

THE evolution of knowledge of the heart and its function may be traced from manuscripts written in the early days of the Greek Empire several hundred years before Christ. Documents from earlier periods are few and inaccurate, although it is certain that the highly developed civilisations in Egypt and Mesopotamia possessed much scientific knowledge which had an important influence on Greek thought. The Ionians were the first Greeks to show an interest in science; they lived about 600 B.C. along the eastern shores of the Aegean Sea in an area bounded by Ephesus in the north and Halicarnassus in the south. Their study of this began when Thales (*c.* 640–546 B.C.), a merchant who lived in the important city of



Map of the Ancient World showing some of the early centres of medicine and science

Miletus, learned about mathematics during his frequent business journeys to Egypt and Mesopotamia. Thales's application of this knowledge to practical problems in his home city led Anaximander (611–547 B.C.) with whom he studied mathematics to use these methods to calculate the size of the heavenly bodies and the distance between them. Anaximenes, born about 570 B.C., inspired by Anaximander's study of the cosmos, began to think about the properties of air, which he called pneuma. Pneuma, which literally means breath, or spirit, he considered to be the substance of the soul and the essence of life. It was soon recognised that this mysterious substance, permeating everywhere and everything, was drawn into the body by the rhythmic movements of the lungs and that its distribution around the body depended on a system of vessels. These vessels were first demonstrated about 500 B.C. by Alcmaeon, a pupil of Pythagoras, in Croton, a city in southern Italy, which was in the area then known as Magna Graeca. Pythagoras's pupils studied not only mathematics but biology and, making use of their remarkable artistic ability, produced intricate and detailed drawings of the external characteristics of animals. Alcmaeon went further than this, as he was the first to practise the scientific dissection of animals, and described the nerves linking the eyes to the brain, as well as the blood-containing vessels which ramify throughout the body. The function of these vessels was further studied by Empedocles, another pupil of Pythagoras, who taught that the blood contains an innate heat essential to life, closely associated with pneuma. He believed that this heat, together with pneuma, emanated from and returned to the heart, by moving backwards and forwards along the vessels in tidal rhythmic pulsations. The first attempt to describe the anatomy of these vessels was made by Diogenes of Apollonia in about 400 B.C.; he considered that they radiated from large vertical trunks and, because of differences in their external appearance, decided that there must be two types of vessel with separate functions. The early biologists soon discovered that some vessels in a dead animal are empty: this is because the last few contractions of a dying heart drive the blood towards the periphery of the body; it led them to the erroneous conclusion that in life also, certain of the vessels only contain air. For this reason they called them arteries.

The scientific importance of cities like Miletus and Croton diminished when Athens, because of its intellectual and cultural development, attracted to it the outstanding Ionian scientist, Anaxagoras (*c.* 500–430 B.C.). He developed a close friendship with the statesman Pericles and the poet Euripides, quickly became an influential person in the city and encouraged progress in scientific knowledge at a time when it was first realised that no one man could compass the whole of knowledge and that it was essential for individuals to specialise. The first two specialist schools in Athens were in medicine and mathematics and, by an extraordinary coincidence, their two leaders had the same name and came from neighbouring islands. They were the physician Hippocrates of Cos and the mathematician Hippocrates of Chios. Hippocrates the physician, born about 460 B.C., developed an outstanding system of medical practice, in which he not only formulated wise principles for the individual care of the patient but also initiated a method of observation from which stemmed many of the great advances in medicine. The accurate deductions of many of his followers were recorded in documents which are still available for our study and in one such treatise the concept that the blood vessels must link together to form a continuous circuit is clearly stated...

> the vessels communicate with one another and the blood flows from one to another, I do not know where the commencement is to be found, for in a circle you can find neither commencement nor end, but from the heart the arteries take their origin and through the vessels the blood is distributed to all the body ... the heart and the vessels are perpetually moving, and we may compare the movement of the blood with courses of rivers returning to their sources after a passage through numerous channels.

It was another two thousand years before William Harvey was able to prove the veracity of this statement.

A document which was even more remarkable for its amazing clarity and accuracy, written by another member of the Hippocratic school and entitled 'On the Heart', describes the heart as a powerful muscle with two distinct ventricles, and observes that the beat of the left ventricle may be felt behind the left nipple. Also, it describes the auricles and gives a detailed description of the structure and function of the valves placed between these chambers. Some authorities consider that this manuscript was written about 340 B.C. by Philistion, a contemporary of Plato, but others think it must have been by another student of Hippocrates and written at a much later period. Although the author obviously had much knowledge of the structure of the heart, he was confused about its function, believing that it was the centre of the intellect and that air in the left ventricle was changed into a special type of pneuma or spirit before being distributed throughout the body; this idea was to persist with even greater elaboration up to the Middle Ages. The studies of the early Greeks were impeded by their not being allowed to dissect human bodies; Aristotle (384–322 B.C.) left wonderful accounts of the structure and function of the organs of many animals, but had an imperfect knowledge of the anatomy of the human heart, believing that it only had three chambers. However, one of his pupils, Praxagoras, who became an important medical teacher in the latter part of the third century B.C., made a detailed study of the pulsation felt in arteries, clearly distinguished arteries from veins, but persisted in the idea that the arteries contain air and that it is only the veins which contain blood.

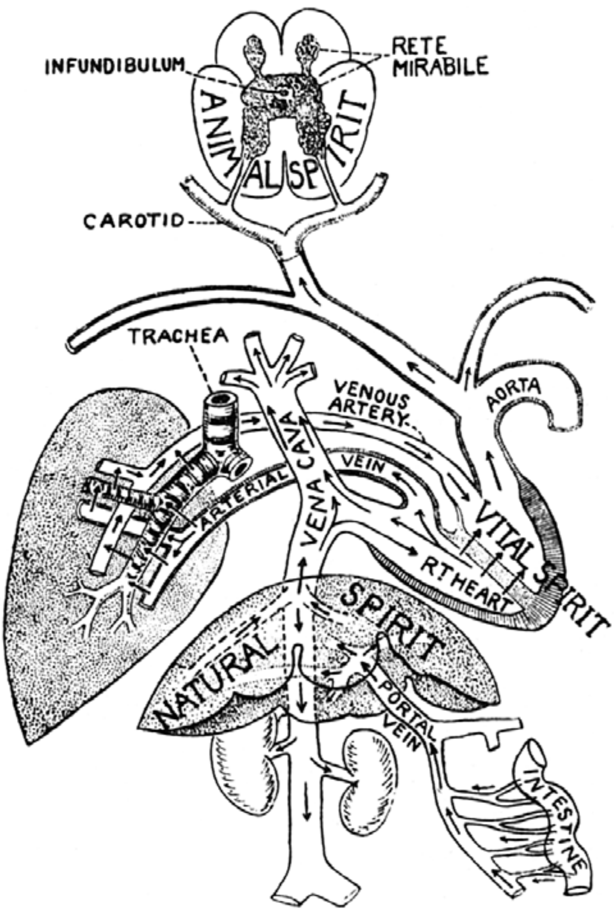
When the importance of Athens as a city of culture diminished, the centre for scientific advance for many centuries was Alexandria. There, the study of anatomy advanced rapidly as dissection of the human body was now allowed. This change of attitude came about because the immigrant Greeks in Alexandria, who were far away from the superstitions and taboos of their native land, increasingly came to accept Plato's philosophy that the human body is no more than an expendable container in which the eternal soul temporarily resides. The first two Greek anatomists to take advantage of this new outlook were Herophilus and Erasistratus. Herophilus, about 300 B.C., developed a remarkably clear understanding of the workings of the heart and blood vessels and appreciated that although arteries are empty after death they contain blood during life, and made a detailed study of the rhythm and rate of the arterial pulse with the assistance of the clepsydra, a Greek instrument for measuring time by the regulated flow of water. Also he gave a most lucid account of the body's use of air, dividing the process into four distinct phases: the absorption of fresh air; its distribution in the body; its return to the lungs; and the exhalation of used air into the atmosphere. Such insight into the complex mechanism of the use of air by the body at that period was tantamount to genius. Erasistratus, his assistant, unfortunately supported the belief that the arteries only contain air. Although he knew that blood spurts from an injured artery, he explained this by saying that the blood must have come from a vein and have been drawn into the vacuum produced by the air escaping from the damaged artery. This ingenious hypothesis, though erroneous, led him to the correct conclusion that the arteries and veins must be connected by a network of minute vessels or capillaries. It was not, of course, until the invention of the microscope, centuries later, that these vessels could be seen. Erasistratus understood that the heart valves ensure unidirectional flow of blood but was prevented from a complete understanding of the circulation by his support of the theory that arteries contain air.

The writings of Herophilus and Erasistratus were lost in the great fire which destroyed the library at Alexandria so that our knowledge of these two men is based on accounts given to us by Galen four centuries later. Galen (A.D. *c.* 130–200), after completing his study of medicine at Alexandria, returned to his native town of Pergamon in Asia Minor, to take charge of the gladiators, an appointment which must have given him much experience in the treatment of wounds.

In the year 162 he moved to Rome where he soon became well known for his skill in the performance of experiments and dissection of animals, whilst at the same time he was greatly respected as a practising physician. His diagnostic acumen from observations of the pulse is well illustrated by an account of his management of two patients. On being called to examine a young woman he noted that she had no fever and a normal pulse rate, except when the name of a certain actor was mentioned, when it increased in speed and became irregular. On two subsequent visits, therefore, he purposely spoke about another actor and observed that this did not affect her pulse, so on the fourth occasion he again mentioned the name of the first actor and from the fact that her pulse rate immediately increased concluded that her illness was of emotional origin and stemmed from unrequited love! The second occasion was when three physicians who, from an examination of the Emperor, Marcus Aurelius, considered he was sickening for a fever, but Galen, from a close observation of the character of his pulse, correctly diagnosed that the Emperor was suffering from no more than a distended stomach from overeating!

Dissection of the human body had once again been forbidden so that all Galen's observations had to be made on animals. He not only dissected but also vivisected many farm animals such as sheep, horses and cows, as well as wild animals, including lynxes, bears, lions and at least one elephant, in addition to birds, fish and snakes. He was a most skilful operator and his enquiring mind led him to conduct most ingenious and carefully contrived experiments to see what happened when muscles were cut, nerves severed, or various tubes and ducts ligated in live animals. From his experiments he learned about the control of respiration and phonation by nerves from the spinal cord, and from ligation of various parts of the urinary tract demonstrated the function of the kidneys. Much of his study

Galen (*c.* A.D. *130–200*) *vivisecting a pig* of the heart's action was done on the exposed, beating hearts of pigs and sheep. It took him some time to develop a satisfactory technique of opening the chest so that initially many of his animals died but with experience he became more successful and in *On Anatomical Procedures* he wrote, '...when the heart is exposed, your task is to preserve all its functions unimpaired, as in fact they are, so that you can see the animal breathing and uttering cries and, if loosed from its bonds, running as before...'. Unfortunately, a pig's heart beats so quickly that he had much difficulty in analysing the movements of its various chambers and the direction in which the blood flowed through them. When dissecting snakes he did not take advantage of examining their slower acting hearts, as did William Harvey fifteen hundred years later. Although Galen came to certain valid conclusions about the heart's action he also made many grave errors. He



Galen's concept of the circulatory system realised, unlike his predecessors, that arteries, as well as veins, contained blood, he had a good understanding that the action of the valves was to ensure unidirectional blood flow, but his teaching was not consistent in this matter for when it suited his purpose he postulated that there could be two streams flowing in opposite directions.

His explanation of the movement of blood was most complex. He taught that chyle from the intestine flowed into the liver, where it was transformed into blood which became imbued at that site with a special type of pneuma called natural spirit; charged with this, the blood was then distributed by the veins to the body. Some of the blood, flowing through one of the larger veins called the vena cava, reached the right ventricle where some, but not all, was directed into what he called 'the artery-like vein' (the pulmonary artery) to reach the lungs; blood from the lungs travelled along what he called 'the vein-like artery' (pulmonary vein) to return to the left ventricle. He somewhat confusingly ascribed three other functions to this vessel, believing that the air inhaled into the lungs from the atmosphere travelled in a separate stream alongside the blood and that it was not until the left ventricle was reached that the blood mixed with the air, with the production of vital spirit. He considered that while most of this spiritous blood was distributed by the aorta to the body a small part of it flowed in the opposite direction along the 'vein-like artery' in order to nourish the lungs and that this stream of blood was accompanied by a separate outflow of waste material which escaped to the atmosphere via the lungs. Although this explanation appears muddled and cumbersome to us, Galen must be given credit for his understanding that waste material is expelled from the lungs, at the same time that fresh air is absorbed. A major error, and one that led him into much confusion, was his belief that the interaction of air and blood takes place in the left ventricle rather than in the lungs. But his biggest mistake was his belief that part of the blood in the right ventricle reached the left ventricle by percolating through invisible pores in the septum separating these two chambers.

Galen expressed his views with strong conviction and it might appear that he inherited the intellect of his father and the domineering character of his mother because, he tells us, '...my father was amiable, just and benevolent, my mother on the other hand had a very bad temper, she used to bite her serving maids and was perpetually shouting at my father'. His teachings, though inaccurate, were accepted as gospel not only during his own life but until the Renaissance.

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Reappraisal during the Renaissance

PROGRESS in medical science in the Graeco-Roman civilisation ended with the achievements of Galen. His belief that his teaching of anatomy was an accurate account of the design of nature as created by God was accepted by Christian, Moslem and Jewish theologians who conferred on his writings a spiritual blessing and religious approbation which made any attempt at contradiction blasphemous and heretical. This attitude naturally removed any further desire for investigation or enquiry and was to bring scientific progress to a halt for a thousand years.

After the fall of the Roman Empire, the Christian Church discouraged orthodox medicine because, although Christ healed the sick, his followers considered that disease was inflicted as a punishment for sin which was only to be expiated by prayer and repentance. This suppressive attitude affected not only medicine but science in general and reached its climax in A.D. 391 when a mob of fanatics set fire to the great library at Alexandria, destroying many priceless treasures of ancient science. Intellectual leadership passed in about the eighth century to people of Arabic speech, including not only the citizens of Arabia but also some Syrians, Persians and Spaniards, whose appreciation of the importance of Greek medicine was far more enlightened. Their physicians, not all Moslems, some Christians, others Jews, were united in their desire to spread the knowledge of medicine and for this purpose translated the works of their Greek predecessors into Arabic. A very influential Arabic scientist and writer in the tenth century was Rhazes, whose greatest medical work *The Comprehensive Book* was one of the most extensive ever written and included virtually the whole of Greek, Syrian and Arabic medical knowledge. A century later another outstanding Moslem, Ibn Sina, known to the Western world as Avicenna, integrated Greek and Moslem medical knowledge in his famous *Canon* in which he reiterated Galen's views, including his description of the heart and lungs. The first person to question Galen's authority was the Arab physician Ibn Nafis who, about the middle of the thirteenth century in his *Commentary on the Anatomy of Avicenna's Canon*, rejected the assumption made by Galen and perpetuated by Avicenna, that there are pores in the interventricular septum through which blood passes from the right ventricle to mix with air in the left ventricle, and expressed his belief that the aeration of blood takes place in the lungs. Such a concept was centuries ahead of its time and because of this was ignored, being unacceptable in the prevailing climate of opinion. Nothing more was heard of this commentary until translated into Latin by Andreas Alpagos and his nephew on their return to Padua in 1520, after spending many years in the East. Recently, Arab authorities have claimed that it was this translation that brought about the anti-Galenic movement in Padua in the sixteenth century but, unfortunately, the anatomical section of their translation cannot be found so that it is not possible to judge the extent of its influence. The original manuscript was rediscovered by an Egyptian medical student Muhyi el din At Tatawi in the archives of the Prussian State Library in 1922. Part of it was then published by him in a university thesis in 1924 and thirty-one years later the entire work was translated into English by E. Bittar, a graduate of Yale Medical School.

The revolt against the unquestioning acceptance of Galen's authoritative teaching coincided with man's determination to escape from the unswerving, narrow, tyrannical attitudes of the Church and the dry, unthinking dogmatism of scholars. This renaissance, as is well known, began about the end of the fourteenth century in Florence and gradually spread across Europe to reach England in the Elizabethan era. This movement, which liberated thoughts and attitudes, led to a reappraisal of science, literature and art. One important change was that the beauty of the human form could now be admired without feelings of guilt or shame, so that artists felt inspired and encouraged to portray its true likeness, but as anatomists, still blinded by prejudice, could not teach them, they had to turn to dissection themselves. Michelangelo, Raphael, and Albrecht Dürer were amongst the great artists who studied in detail the bone structure and contours of the superficial muscles but the most outstanding was Leonardo da Vinci (1452–1519) who, not content with this, dissected the deeper structures of the body. His original, enquiring mind led him to be a brilliant inventor as well as a great anatomist and artist. His knowledge ranged over all branches of science from mathematics to physiology, though often his grasp of principles was far ahead of the time when they could be of practical use. Thus he designed a parabolic compass and made drawings of quick-firing and breech-loading guns long before technical skill permitted their

Self-portrait of Leonardo da Vinci (1452–1519) manufacture. His study of flight in birds led him to devise a model of a flying machine and to plan the construction of a helicopter and parachute. As engineer in charge of the maintenance of the waterways in Lombardy, he studied the mechanical principles underlying the movement of water in rivers and streams by making model glass channels and observing the flow of water with the help of added millet seeds, fragments of papyrus and seeds of panic grass '... so that one can see the course of the water better from their movements'. It was these same methods which he was to use in later years when he came to study the action of the heart.

Contrary to Galen's belief, Leonardo was quick to realise that the heart is made of muscle which acts as a pump so that blood which flows into it in its relaxed state (diastole) is forced out under pressure when it contracts (systole). His great interest in hydrodynamics and his genius for invention led him to devise working models whereby he could simulate the action of this pump and study in particular the movement of the valves, without having to resort to vivisection, a practice which he strongly abhorred. It was the valve at the mouth of the aorta which he studied most intensively and he showed that when a stream of blood enters the aorta from the left ventricle the valve shuts immediately to prevent the blood regurgitating. This is now relatively easy to demonstrate by ciné-radiography after the injection of radio-opaque dyes into the circulation, but for Leonardo it was a task which demanded consummate skill and ingenuity. First he made a solid cast of the aorta by pouring wax into it from above and allowing it to flow through the valve opening into the heart. From this he prepared a hollow cast of gypsum which he lined with a sheet of blown glass. Then he fashioned a cast of the valve which he incorporated into this glass mould in order, he said, 'to see in the glass what the blood does in the heart when it shuts the opening of the valves'. Both from his observations of dissection specimens and study of his cast, he learned that the aorta is of triangular shape and that its mouth where the valve cusps are inserted is widened by three flanges, later to be known as the sinuses of Valsalva. With his glass model and the use of grass seed he performed experiments from which he deduced that when blood is ejected into the aorta turbulence is set up so that, in addition to the main jet, there are three vortices which by a backward sweep into the sinuses of Valsalva close the valve cusps by sideways pressure. He went to much trouble to demonstrate this phenomenon in his drawings and to point out that the valve cusps could not be closed by simple vertical pressure from the weight of the main stream of blood above them as this would cause them to buckle. It is incredible that Leonardo learned all this from the movement of grass seed in a