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MEN AND BOOKS

Man's Changing Concepts of the Heart and Circulation

MARTIN H. ATKINSON,* *Calgary, Alta.*

THE functions of the heart and blood have intrigued man throughout the ages. The earliest records of the cardiovascular system occur around the year 500 B.C., in the writings of the early Greek philosophers, before the time of Hippocrates. During that period, the school of Pythagoras was situated in the south of Italy, where two of his pupils were closely identified with medicine. The first was Alcmaeon, who is credited with the first distinction between arteries and veins; he investigated the action of the blood, believing that it withdrew from the brain during sleep and flowed toward it during wakefulness. The second pupil was Empedocles who, like his contemporaries and predecessors, adhered to the theory of *pneumatism*, which is the belief that the phenomena of life are associated with the presence of a subtle vapour, vital spirit, or "pneuma" which penetrates the organism and causes its movements. Empedocles believed that the heart was the organ which distributed the pneuma throughout the body. This pneuma supposedly entered the body by way of the lungs and also through the pores in the skin, which he thought were joined with "bloodless tubes" (end arteries) beneath the skin.

At the time of Hippocrates, who lived between the years 460 and 370 B.C., Greek medicine dominated the world. A most important contemporary of his was Aristotle, pupil of Plato. Aristotle did not perform human dissections but carried out extensive dissections on animals. He gave fairly accurate descriptions of the great veins and the superficial vessels in the forelimb. Aristotle conceived the brain to be a mechanism for cooling the heart, by the secretion of phlegm (pituita). He was not aware of a distinction between arteries and veins.

About 300 B.C., around the time of the conquests of Alexander the Great, a great medical school was founded at Alexandria in Egypt. Two great teachers there were Herophilus and Erasistratus. Herophilus was probably the first man to dissect cadavers in public. He counted the pulse, timing it with a water clock; he commented on the systolic and diastolic phases, and taught that the pulse had four qualities: rate, rhythm, size and strength. Erasistratus, whom Singer calls the "Father of Physiology", believed that every organ is equipped with three "vessels", artery, vein, and nerve, which divide to the limits of vision and beyond. These minute endings, plaited together, form the tissues, nourished by the vein contained within it. The minute endings of vein and artery are situated close together in what are known as "synanastomoses"; they do not, however, communicate, nor is there any passage of blood between vein and artery under normal circumstances. Blood, essential for nourishment, is formed in the liver from digested food products carried there via the portal vein. From the liver, the blood goes to the right ventricle, whence it is conveyed to all parts of the body via the venous system (Fig. 1). Air

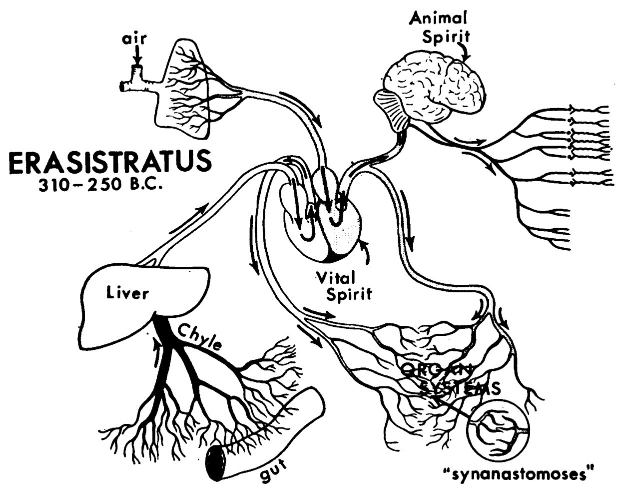

Fig. 1.—The movement of the blood according to Erasistratus.

enters the lungs via the bronchi, and passes through the pulmonary vein to the left ventricle, where, by some mysterious process, it is changed into the vital spirit, necessary for metabolism. The vital spirit is thus distributed to all parts of the body by way of the arterial system. That part of it which reaches the brain is changed within the ventricles to animal spirit, necessary for motion and sensation. This spirit in turn is transmitted to all parts of the body through the nerves, which Erasistratus thought to be hollow during life but solidified after death. At the end of the vascular system both pneuma and blood are used up in the process of nutrition or voided by excretion, so that there is nothing left to return to the heart. Consequently, there was no need to account for a system of circulation. Erasistratus also discovered the function of the heart valves, which was to prevent regurgitation of blood—and also, he thought, pneuma—back into the heart.

Erasistratus believed correctly that the arteries pulsated in a passive response to the blood being

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*Fourth-year medical student, University of Alberta.

pumped into them from the heart. In other words, the heart fills because it becomes dilated; the arteries dilate because they become filled. As can be seen, Erasistratus thought veins alone carried blood and that arteries were filled with pneuma. This idea was based on the postmortem findings of arteries filled with air and veins containing pooled blood. He explained the fact that severed arteries bled because the escaping pneuma created a vacuum which, being "incompatible with nature", was filled with blood drawn from the veins across the synanastomoses. It was Galen, 450 years later, who proved that arteries did not contain air alone.

Claudius Galen (130-200 A.D.) of Pergamon in Asia Minor was, after Hippocrates, the most eminent of the ancient physicians and one of the greatest biologists history has ever known. In the time of Galen, human dissection was frowned upon and most anatomical knowledge was gained from dissection of the Barbary ape, which was prevalent around Pergamon during that period. For this reason, Galen's knowledge of the anatomy of the blood vessels and heart was limited. For him, the heart consisted of two ventricles, the atria being dilated parts of the pulmonary vein and vena cava. He disproved the theory of Erasistratus that arteries contain only air or pneuma and that blood enters only after incision. He took an artery and tied two ligatures a few inches apart and then incised the artery. Blood flowed out and, since it could not have entered past the ligature, it must have been present all the time.

Galen's theory of blood movement was a modification of that of Erasistratus (Fig. 2). He believed as did certain of his predecessors, that there was a pneuma which was the essence of life and that it was of three kinds. Digested food substances were conveyed to the liver as chyle via the portal vein, where they were elaborated into blood and endowed with the natural spirit, necessary for growth and nutrition. This blood was distributed to all parts of the body by *ebbing and flowing* within the caval system, which he thought arose as a single vessel from the liver, giving off ascending and descending branches. The blood which reached the right side of the heart had two fates: the greater part of it flowed through the pulmonary artery to the lungs where impurities were given off and exhaled, while the purified blood ebbed back to the heart and then into the general circulation; a small portion of this purified blood seeped across the inter-ventricular septum through minute pores. (What he probably saw were recesses between the trabeculae carnae.) It trickled into the left ventricle where it mixed with air drawn from the lung via the "rough artery" (trachea) and pulmonary veins. From this mixture was produced a higher grade of blood charged with the vital spirit, which ebbed to and fro within the arteries, and was necessary for the metabolism of the body. That blood which reached the brain was charged with the third

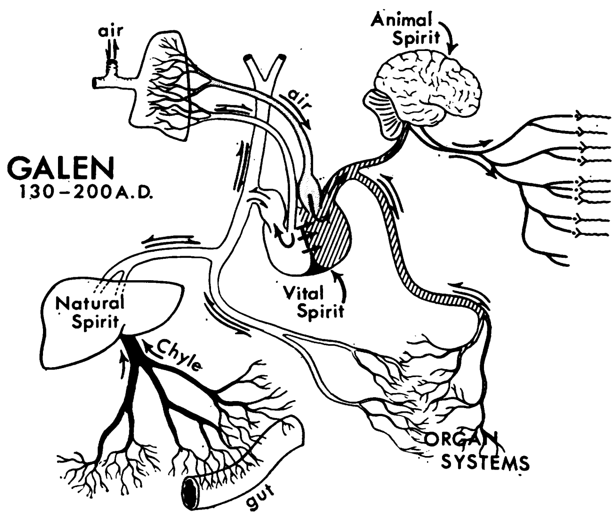

Fig. 2.—Galen's concept of blood movement. Note the similarity to the scheme of Erasistratus.

pneuma, the animal spirit, which was distributed to all parts of the body via supposedly hollow nerves, endowing it with motion and sensation.

Whereas Erasistratus had correctly believed in the passive pulsations of the artery with each heartbeat, Galen held that the heart and arteries were closely connected by some nervous mechanism so that their motions were simultaneous and identical; thus when the heart contracted, the vessels actively dilated at the same time, drawing the blood into them.

With the death of Galen in 200 A.D., the study of anatomy and physiology ceased almost completely and the curtain descended on what was later to be known as the Dark Ages. For over a thousand years the teachings of Galen were accepted without question. The reasons for this are obvious: Galen regarded the body as the temple of the soul, in line with the teachings of Christianity. His authority received important support from the Church, and this involved two important factors which were among the greatest hindrances to man's scientific advance up to the time of the Renaissance. First, dissection was considered to show a lack of respect for the human body. Secondly, the great Councils of the Church defined within narrow limits the mode of thought allowed. Faith alone was the foundation of knowledge.

The fifteenth century, with its rebellion against the Church, brought a revival of critical thought and of ancient scientific knowledge. Naturalism, born in the thirteenth century, came to maturity; artists realized that, to show the true beauty of the human body, a knowledge of anatomy was needed. No one could be considered an accomplished artist unless he had first dissected; therefore artists turned to dissection to improve their art. The most important of these artists was Leonardo da Vinci (1452-1519). Born the bastard child of a dairymaid, he was later adopted into the esteemed family of his true father. He was the most

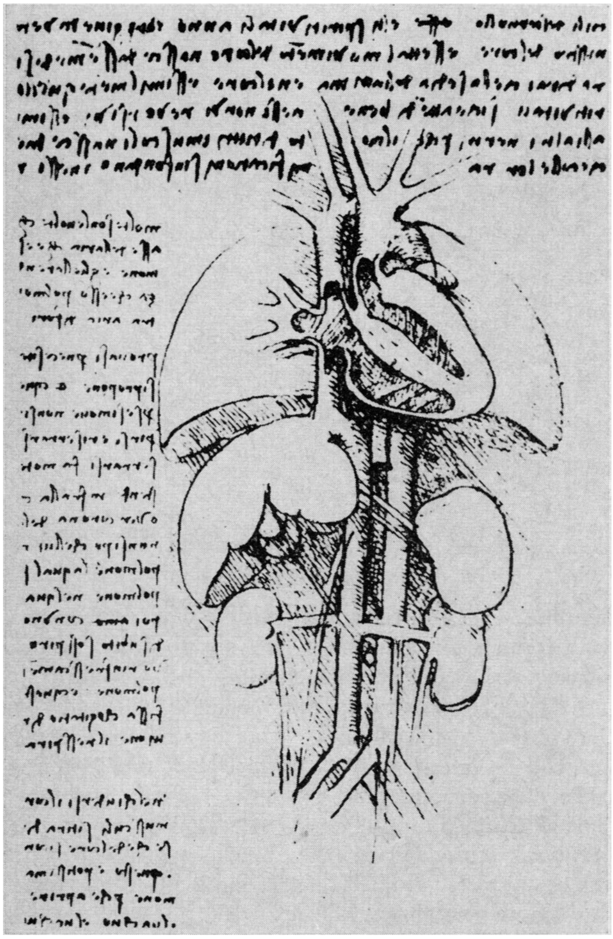

Fig. 3.—Sketch of the heart and great vessels showing the moderator band.—Leonardo da Vinci.

Fig. 4.—Illustration of the heart, showing pores in the interventricular septum.—Leonardo da Vinci.

important physiologist and greatest artist of his time—the "Father of Medical Illustration".

Although he began to dissect mainly to improve his art, he became interested in the structure and workings of the human body *per se*. He made admirable drawings of the circulatory system, the best being those of the heart, which he shows as a four-chambered organ, thus differing from Galen. He is also given credit for the discovery of the moderator band which is depicted in many of his sketches (Fig. 3); however, he could not emancipate himself from the old idea of pores in the interventricular septum, clearly seen in some of his drawings (Fig. 4). Da Vinci had noticed that milk being churned by dairymaids became heated by the action of the churn. He deduced that, in the same manner, the movement of the heart heated the blood within its chambers. He identified this heat with the vital spirit of Galen and others. The heat vapourized some of the blood, converting it into air which, mixed with blood and heat, was transported to all parts of the body via the arteries, thus giving life in the form of heat. At the terminations of the capillaries, the vapour condensed through the pores in the form of perspiration. He presumed that a fever was due to tachycardia which produced more heat.

Da Vinci proposed that the left ventricular wall was thicker than the other chambers in order to resist the higher degree of heat found there. This is in contradistinction to the opinion of previous authors who thought that the increased weight of the left ventricle, along with the spleen, counterbalanced the weight of the liver on the right.

Da Vinci inflated the lungs and found that, no matter what force he used, air could not be driven from the air-tubes into the heart. He therefore inferred quite correctly that the pulmonary vein did not transport air to the heart as Galen and his followers believed. Instead the lungs served to cool the blood brought to it and also to cool the heart directly.

Although he made many discoveries and observations, da Vinci never published his works. It was for Andreas Vesalius of Brussels (1514-1564) to demonstrate his own magnificent gifts of observation and description in his two epic books, "Fabrica" and "Epitome". Vesalius studied first at Paris under Sylvius and later took the professorship at Padua, Northern Italy, at the age of 24 years! Although Vesalius was considered one who placed his study on a firm foundation of observation, there were really few opportunities to obtain bodies for dissection; therefore Vesalius' anatomy

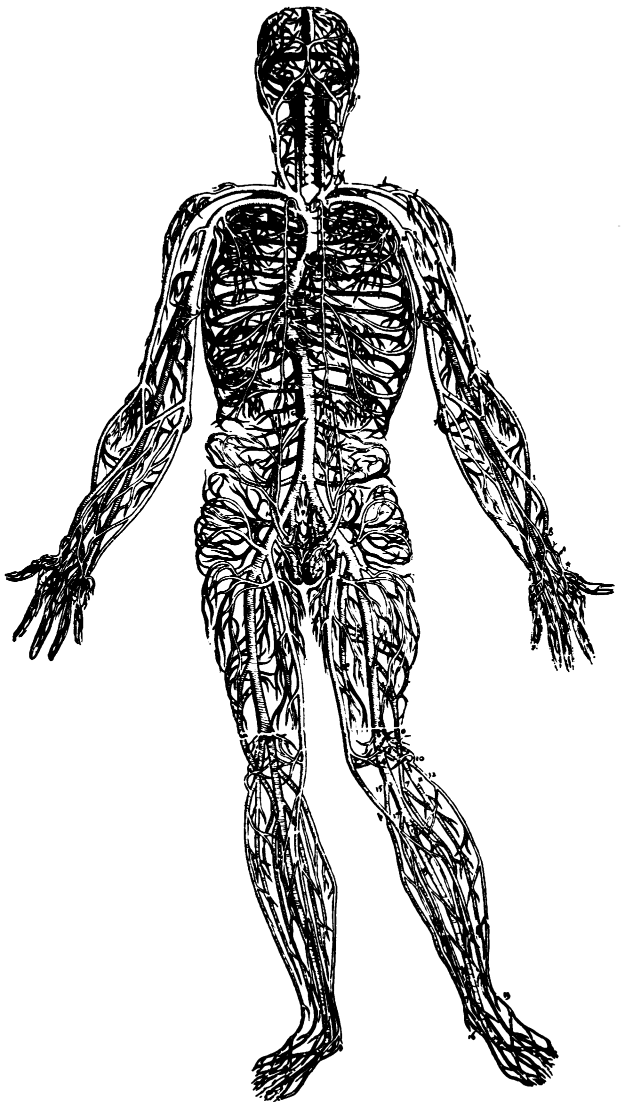

Fig. 5.—Vesalius: the venous system.

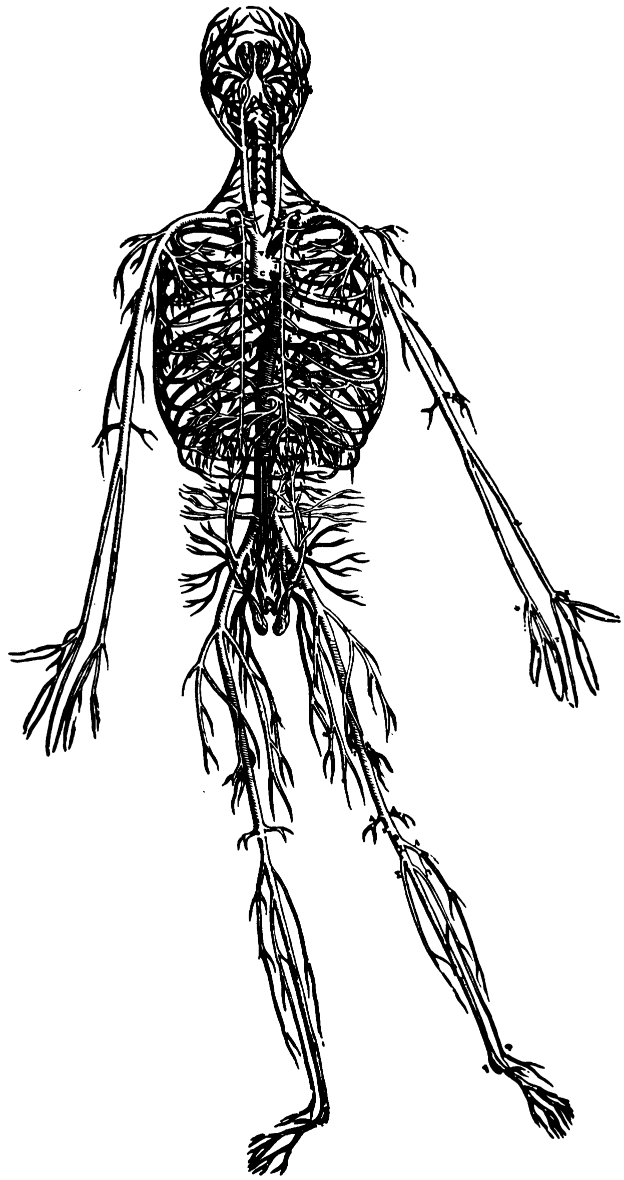

Fig. 6.—Vesalius: the arterial system.

consisted of an admixture of human and animal dissections, especially of the Barbary ape which was common in Europe at that time. Vesalius, in his studies, came to doubt many of the old claims of Galen and Aristotle. He was the first to deny openly the old Galenic concept that the interventricular septum had pores. The publication in 1543 of his famous work "Fabrica", in seven books, marked the beginning of modern science. The third book contained the treatise on the cardiovascular system, with beautiful engravings by a contemporary artist, Stephen Calcar. Two plates worthy of mention here are those of the venous and arterial systems.

In the general scheme of the venous system as described by Vesalius, several unusual features can be noticed (Fig. 5). The vena cava is depicted as a single vessel with the right atrium connecting superior and inferior halves. Vesalius did not believe, as did Galen, that the vena cava originated in the liver; in fact he went to great pains to disprove this by dissection and postulate the heart as the origin of the vena cava. The arrangement of the veins at the base of the neck is certainly not human, and suggests the brachiocephalic vessels of lower animals. The non-human position of the renal vessels can be noted, the right being higher than the left, as derived from the opinions of Aristotle and Galen. Oddly enough, Vesalius shows the external jugular vein to be larger than the internal, once again showing the old Galenic influence. The venous system is shown in far more detail than the arterial system because of the prevalence of venesection, practised during those times.

The arterial system, in contrast, is glossed over, the major vessels being the only ones shown (Fig. 6). The branches of the aortic arch, as he illustrates them, are a rare occurrence in man and suggest those of the ape, from which Vesalius gained much information. The lateral thoracic artery is shown excessively large for man, and suggests that of the

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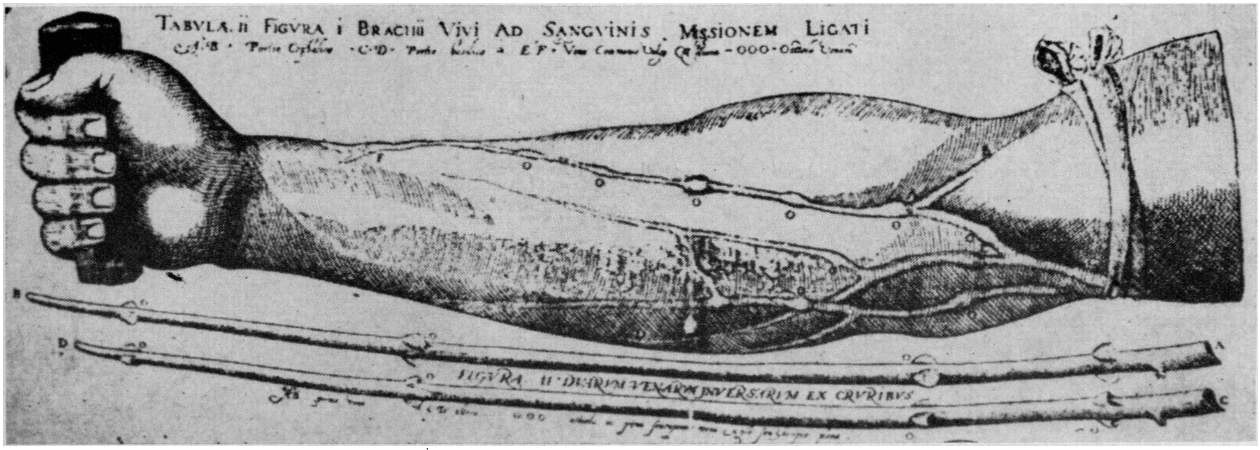

Fig. 7.—Illustration from Fabricius: "On the Valves of the Veins".

dog or pig. The pear-shaped bodies in which the internal carotic arteries terminate are the choroid plexuses. As with the venous system, the levels of the renal arteries are reversed. It is difficult to see how such preparations could have been made, save by injection. Despite his astute anatomical observations in man and animals, Vesalius had no conception of the circulation of the blood.

Another great contributor of this era was Fabricius of Aquapendente (1533-1619), who succeeded Vesalius at Padua in 1565, upon the latter's death. His greatest claim to fame is that he was the tutor of William Harvey. The best-known work of Fabricius is that "On the Valves of the Veins" (Fig. 7). There is no doubt that a number of anatomists before him, including Vesalius and Eustachius, had seen the valves; Fabricius, however, explored and described them better than anyone else had done before this time. He stated correctly that the mouths of the valves are always directed toward the heart; nevertheless, he had no inkling as to their true function and believed that they slowed the blood as it flowed toward the periphery so that it would not pool in the extremities.

Up to this time, even with the rebirth of scientific learning, the views of Galen were accepted as they had been for fourteen and a half centuries, despite the claim by so eminent a man as Vesalius that the pores in the interventricular septum did not exist. It is Harvey who is generally given credit for the first clear concept of the circulation of the blood.

William Harvey (1578-1675) was the eldest of seven sons of Thomas Harvey, a merchant. He went to Padua as a boy and studied under Fabricius, whose work had a great influence on him and stimulated an intense interest in the movement of the blood. Upon his return to England, Harvey began experimenting and dissecting in earnest. By 1615 he had obtained a clear concept of the circulation of the blood, based a great deal on the valves of the veins, so ably described by Fabricius. In 1628 he published his classic work: "De Motu Cordis et Sanguinis". The figures he used in this book are not his own but were taken from the works of his great master, Fabricius (Fig. 8).

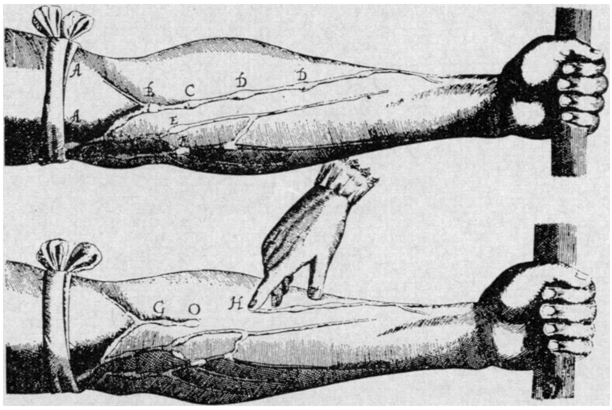

Fig. 8.—Classic illustration from Harvey's "De Motu Cordis".

It was by an ingenious set of deductions that Harvey disproved the age-old concepts of Galen; a description of these is beyond the scope of this paper. It should be enough to note that he proved that the left ventricle, pumping three thousand times per hour, ejecting two ounces of blood per contraction, threw more than three times the body weight of a man into the great artery in one hour; obviously the blood could not possibly come directly from ingested food and drink as Galen thought. No one could consume so much in one hour. There was only one conclusion to be drawn, and Harvey drew it: the blood, sent out continuously through the aorta, could only have come from the veins. He finally came to the conclusion that the movement of the blood was circular. The concept of circulation was born.

Although Harvey demonstrated the circulation of the blood, he left open the question as to whether the blood, passing from veins into arteries, is retained in vessels or passes into pores and cavities in the tissue. It was for Malpighi (1628-1694), 33 years later, to supply the "missing element" by describing the capillaries in the lung of the frog in 1661. Harvey's discovery of the circulation of the blood has been the basis of modern physiology and rational medicine.

Following the epic-making discovery of Harvey, further additions to our concept of the cardiovascular system seemed to centre around microscopic anatomy of the heart. It was Scarpa in 1794 who gave the most adequate description of the cardiac nerves, and Purkinje in 1893 who demonstrated the terminal fibres of the conducting system in the subendocardial layer of the myocardium. Wilhelm His in 1893 described what he thought were specialized bundles of fibres which connected atria and ventricles, now called the Bundle of His.

With the advent of the twentieth century, thought turned to the physiology and pathology of the heart. For many years it had been known that muscle tissue has the inherent ability to produce and transmit electrical impulses. In his classic paper of 1903, Einthoven (1860-1927) introduced the string galvanometer, which registered the current produced by the heart's contraction. Another great man of this century was Sir James Mackenzie (1853-1925). Mackenzie's name is associated with two works—his "Study of the Pulse", which contains a keen analysis of the different kinds of pulses; and "Diseases of the Heart", dealing with cardiac arrhythmias, separating them into types. This latter work brought him real fame and revolutionized concepts of cardiac disease. Probably one of the greatest men of this century was Sir Thomas Lewis (1881-1945). In 1910 he proved, using Einthoven's string galvanometer, that the cardiac impulse had its origin in the sinoatrial node, described previously by Keith and Flack in 1907. He conceived the brilliant explanation for atrial fibrilation and flutter as a circus movement of an excitatory wave around the mouths of the great veins. During the First World War he took charge of the study of "soldier's heart" which he later renamed the "effort syndrome", seen so commonly today in the office of the cardiologist and internist. For this work he was knighted in 1921.

In retrospect, we can see how the various theories of the Greek physicians dominated the world for over a thousand years. That this was so is not surprising, if we remember that their explanations were plausible when viewed against the background of the age. It wasn't until about five hundred years ago that thinking came to be based on inductive rather than deductive reasoning. It took the Renaissance, with its spirit of inquiry, to make a reassessment of past beliefs and to open the way for Harvey and his predecessors to unravel the mysteries of circulation. No longer were the facts made to fit the theory; the facts were explained in terms of the theory. The new scientific method served to correct the errors of the past and culminated in the classic work of Harvey.

In such a short paper it has not been possible to give deserved mention to all the men who contributed to our present knowledge of the cardiovascular system; only the outstanding figures have been touched upon. The main objective has been to show that the understanding of the cardiovascular system was not a "discovery", but rather a "development"—not the work of one mind, but of many. It has changed with changing times, and evolved finally into the intricate and intriguing study which it is today.

1305 Frontenac Ave.,
Calgary, Alta.

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PAGES OUT OF THE PAST: FROM THE JOURNAL OF FIFTY YEARS AGO

THE CANADIAN PRACTITIONER'S DIAGNOSIS OF PULMONARY TUBERCULOSIS

In the opinion of the Canadian sanatorium physicians (and I may here state that the answers I have received from a number of the prominent men in the United States are in all respects similar to those I have presented above, and are in terms even more vigorous and unmistakable), in the opinion of these workers, the Canadian practitioner is diagnosing the commonest disease in Canada in a manner that, were it any other disease, would stamp him as careless and inefficient. There has been so much written of late on the dangers of tuberculosis, so many warnings have been uttered, that I think our physicians have come to look with a mild contempt on it all, that they do not consider tuberculosis of the lungs either a difficult disease to diagnose, or a difficult one to treat. It is the every-day experience of the sanatorium physician that they are doing neither the one nor the other properly; that they do not recognize the disease until it is well advanced; and then often fail to regulate the life of the patient intelligently enough to effect an arrest of the disease.—A. F. Miller, *Canad. Med. Ass. J.*, 4: 797, 1914.