Historical Perspective

Galen's (130-201 AD) Conceptions of the Heart

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In the 2nd century AD, the prolific Greek physician Galen contributed significantly to the anatomical and physiological knowledge of the cardiovascular system. However his erroneous theory of blood circulation, based on the inaccurate notion that venous blood passes through tiny pores in the heart's septum, moves from the right ventricle to the left, and is mixed with inhaled air from the lungs, was to block any new ideas in this field for more than 1500 years.

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Ancient civilisations recognized the heart as the mechanism by which the blood was delivered to the tissues. However, the pathway of the blood circulation was less understood.

In the 3rd century BC, the distinguished Alexandrian anatomist and physiologist Erasistratus of Chios (310-250 BC) contributed considerably to the knowledge of cardiac anatomy and, in mechanistic terms, very closely approached the blood circulation theory. As he defended the idea that arteries contained *pneuma* (air) and that blood circulated only in the veins, he failed to discover blood circulation. Furthermore, he described the route of blood from the liver to the heart through the inferior *vena cava*, and from the heart to the lungs through an arterial vein (pulmonary artery); he was also the first to report the role of the tricuspid and pulmonary valves.[1,2]

Centuries later, these views were refuted by Galen (130-201 AD), a prominent figure in medicine. Galen was born at Pergamum in Asia Minor and his father Nicon, a wealthy architect, supervised his education. Initially, he studied medicine in his native city, then in Corinth, and finally in Alexandria (Figure 1). Returning to Pergamum, he was appointed as a city physician to the School of Gladiators but he gained such a reputation and success that he soon became the court physician of the Roman Emperors Marcus Aurelius and Lucius Verus.[3]

Galen, a follower of the Hippocrates' humoral theory, believed that the four humours of the body (phlegm, blood, black bile, and yellow bile) were responsible for health or illness. Going further, he classified all personalities into four types: phlegmatic, sanguine, choleric, and melancholic – terms still used to characterise dispositions. Imbalances among these humours would lead to disease and could be corrected by adding, not only herbal extracts of similar origin, but also other extracts with opposite properties.[4]

Galen wrote a great number of treatises on medical and philosophical subjects and his doctrines dominated medical thought until the 16th century.

Galen on cardiac anatomy

Galen describes the pyramidal or conical shape of the heart and its position in

Figure 1. The distinguished physician Galen (Singer CJ. The evolution of anatomy. London: Kegan Paul, Trench, Trubner; 1925. p.48. Source: Wellcome Library, London).

the thorax. The pericardium surrounding the heart is a protective shield. He describes the position of the great vessels at the base of the heart, the arterial vein (pulmonary artery), the aorta and the venous arteries (pulmonary veins).[5]

He devoted particular attention to the structure of the heart muscle: "The heart is a hard flesh consisting of straight, transverse, or oblique fibres of various kinds. The substance of the heart was created to be strong and resistant".[6]

Galen, like other physicians of his time, knew that the heart had four cavities, but like Erasistratus, he regarded only the ventricles as forming the heart proper and the atria as being a sort of enlargement or bulge of the vessels leading into the ventricles. He points out the presence of four openings in the ventricles, two in each cavity: one to introduce the blood, the other to expel it.[7] The difference between the thick structure of the left ventricle in contrast to the thin of the right impresses him. At the base of the left ventricle, he writes, there is a large hole that comprises three sigmoid membranes and opens into the great artery (aorta), giving rise to all the arteries.[8] He believed wrongly that there was communication between the right and left ventricles because of perforations in the septum, a notion that misled the medical community for centuries: "The small *fossae* which appear, especially in the middle of the separation (both ventricles) of the heart, have been created for communication (...), which exists for the mutual exchange of blood and pneuma".[8]

He emphasised, though, the difficulty of identifying them because of their fineness and because "the corpse is cooled and collapsed".[8]

Galen considers the auricles as part of the vessels impinging on the heart. They are reservoirs of blood that propel their content into the heart. Moreover, he mentions the sigmoid valves, the *trabeculae carnae,* the aorta and the right atrioventricular tricuspid valve.[9]

Galen on vessels and pulse

Contrary to Erasistratus, Galen was the first to determine that arteries carried blood and not air: "Arteries contain blood, preserved pure". Furthermore, he tried to solve a physiological problem concerning the origin and nature of arterial pulsation: Do arteries pulsate because they are elastic tubes that passively dilate as they are intermittently inflamed by fluids or do they pulsate because their walls actively contrast and dilate in response to a stimulus or power that originates in the heart? Thus, he performed his famous experiment, which is described in his book *An in arteriis natura sanguis contineatur*: He placed a tube within the lumen of an artery so that the flow of the blood was unobstructed. He found that the pulse wave was also transmitted normally but when a ligature was tied round the artery, over the tube, the pulse could no longer be felt in the distal part of the vessel. He concluded that the arterial pulse was not caused by the filling of the arteries but by an impulse passing along the arterial wall.[10]

Galen's experiment was repeated several times over the following centuries: Andrea Vesalius (1514-1564) obtained similar results; William Harvey (1578-1657) reported that he had found pulsation to continue distally after the ligature had been tied over the tube; Raymond Vieussens (1641-1715) repeated the experiment in Montpellier in 1680 and failed to confirm Galen's findings;[8] Alexander Mavrocordatos (1636-1709), physician and dragoman of the Sultan Mehmed IV, admitted that the majority of physicians of his time believed that the arterial pulse was due to an impulse of the blood, but he rejected this idea, concluding that the pulsation was due to the pulling of the heart on the aorta and the subsequent spreading of the movement to all arteries.[11] In the 20th century, the experiment was repeated by Forrester in 1954 and Amacher in 1964, who did not confirm Galen's results. In 1966 Malato and Scarano reached a different conclusion: they found that the distal pulsa-

tion ceased immediately when the tube was inserted and tying the ligature made no difference.[8]

Nowadays, there is no obvious explanation for these divergent results, as performance of the experiment presents difficulties.

Moreover, Galen accepted not only the anatomical difference between arteries and veins established by Herophilus but also the existence of capillaries (proposed also by Erasistratus) as invisible structures.[9] He describes the coronary vessels quite well: "the veins that nourish the heart spring in all animals from its cavity. People speak of them as *enwreathing* the heart since two of them do so surround it, just as two arteries (that arise from the aorta in its first part, immediately after it leaves the semilunar valves) come down from the left part into the substance of the heart (coronary artery). They are best examined in the detached heart, especially in large animals, but they are the same in all and do not differ according the size. It is, however, easier to see them clearly in large hearts".[12] He believed, however, that the coronary veins, not the coronary arteries, nourish the heart by conveying blood to it.[8]

Galen is prolific in the study of the pulse, as he wrote eighteen works. We may find a detailed description in which he attempts to define length, breath, depth and regularity by distinguishing several varieties: *longus*, *brevis*, *altus*, *humilis*, *celer*, *vehemens*—verbiage that provides little specific information. In addition, he recognises certain variations and the pulse is described with picturesque names: *pulsus formicans* (ant-like), *araneus* (cobweb-like), *myurus* (mouse-like), etc. Referring to speed and frequency he mentions that it can be frequent (*pyknos*), medium, or rare (*araios*).[7,8] He noted irregularity of the heart rhythm as understood today and regarded "an intermittent" pulse, probably due to extrasystoles, as a sign of poor prognosis.

Galen on circulation

One of the most debated questions in the history of blood circulation is Galen's discovery of the lesser circulation. As was suggested by several authors, Galen was the first to describe the passage of blood from the left to the right ventricle through the lungs.[13]

After Galen, arteries carried from the heart to the periphery not only blood but also "*pneuma*". He recognized three "*pneumas*", one arising from the liver (natural *pneuma*), the second from the heart (vital *pneuma*), and the third from the brain (animal *pneuma*). He attributed to the liver a prominent role, inherited from the Babylonians' theories, according to which it was a nourishing and distributing organ.[8] Galen believed that blood produced by the liver was distributed to the entire body through the veins and that it reached the right heart through the inferior *vena cava*.[13]

He thus describes the motion, without recognising the pumping action of the heart. The blood was propelled inside the vessels by attraction from the peripheral tissues in need of nutrition or by squeezing of vessels by thoracic respiration. He states that: "The heart dilates when it wants to draw some useful substances; it withdraws upon itself as it wants to benefit from the attracted substances, and then it contracts to expel the residue of these substances".[8]

According to his conception of circulation: "the stomach and intestines receiving the food, are at the origin of the system which, by the gastric and intestinal vessels, forwards these foods to the liver gathered in the portal vein. The liver elaborates the venous blood, which by the hepatic veins, is discharged into a short *cava* which is subdivided into two branches: the one, which is descending, will carry the venous blood to the lower half of the body; the other, which is ascending, will raise the blood to the upper half".[6]

The blood's distribution in the arterial tree was ensured by the capillaries: "All over the body the arteries and veins communicate with one another by common openings and exchange blood and *pneuma* through certain invisible and extremely narrow passages".[9]

The quantity of blood that passed through these invisible openings, however, was too small to account for the blood in the arterial tree; most of the blood passed from the right heart to the left through invisible openings in the interventricular septum.[8]

So Galen introduced another element: a small part of the right-heart blood reached the left heart through what we would call the lesser circulation.[13]

The nutrition of the lung is partially provided by the arterial vein (pulmonary artery), as mentioned in many places. Nevertheless, this supply is not sufficient, because the wall of the pulmonary artery is too thick, and it is ultimately the venous artery (pulmonary vein) that performs the most sufficient supply, thanks to its thin coat.[8]

Moreover, there is a perpetual back and forth motion in the pulmonary vessels: "When the lung dilates, the blood flows and fills the veins of the lung; when it contracts, it acts as a reflux that moves inces-

santly, just like the waves in a strait, and consequently giving to blood a back and forth movement that is by no means auspicious. As for the venous artery, it brings the *pneuma* to the left ventricle, but it is also, as we know, to let the "fuliginous residue" pass from the heart to the lungs of the left ventricle".[6]

Galen thought that most of the blood going through the pulmonary artery was consumed by the lungs for their nutritional needs, that only a trickle would pass from there to the pulmonary veins and into the left ventricle and that almost all blood going into the left ventricle came directly from the right ventricle through *foramina* in the interventricular septum.[6]

Finally, the foetal circulation as described by Galen summarises how he observes clearly but misinterprets. He claims that the content of the pulmonary vessels is reversed in the foetus. In fact, for him, the "right" blood of the *vena cava*, the blood responsible for the natural spirit, goes back to the lungs by what became known as the *foramen ovale* (*foramen Botalli*), then the venous artery (pulmonary vein), while the "left" blood, which is responsible for the vital spirit, reaches the lung by the arterial vein (our pulmonary artery) thanks to the aorta and *ductus arteriosus*.[14]

Discussion

Given that Galen's anatomical knowledge comes from animal vivisection and rarely from observing human injuries and autopsy studies, his errors were due to the application in humans of many traits of animal anatomy.

Galen's contributions to the field of cardiovascular therapeutics are moderate. He attempts to apply the Hippocratic doctrine of treatment by opposites. This attitude was doomed in advance, because he completely ignored what a disease actually was and what could be its opposite. Galen sought to determine the activity of some remedies, their relation to the four fundamental properties of humours, their elimination, becoming the first duty of the physician. An important point is that Galen insisted on the fundamental role of diet. Among the numerous recommended substances, the most effective according to him was the poppy. The treatment was based on depletion, bleeding, purging, cupping, and diuretics, which help remove the excess of blood, water, bile and phlegm.[15]

Conclusion

Although Galen was a great anatomist, he was a bad physiologist (mainly because of his tendency towards imagination rather than objective approach), but a good medical semiologist and therapist, in harmony with his beliefs on the human body. Galen's work on the heart, despite the errors and curiosities, managed to predominate from late antiquity through the entire mediaeval period and up to the Renaissance in Western and Arab cultures, thus demonstrating the power of habitual thinking in the sciences.

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