THE CARDIAC ANATOMY AND LEONARDO DA VINCI

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Leonardo da Vinci (1452-1519) was not only a superb painter and sculptor, he also was an architect, a mechanical and hydraulic engineer, as well as the founder of the functional anatomy. Leonardo correctly deduced the functional anatomy and physiology of the heart, reaching conclusions that are still being verified in the light of modern research.

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Leonardo da Vinci (1452-1519) was not only a superb painter and sculptor, he also was a Renaissance man in the true sense of the word: an exceptional architect, a talented mechanical and hydraulic engineer, as well as the founder of the functional anatomy [1]. He founded iconographic and physiologic anatomy. Leonardo admitted to performing more than 100 human dissections; among the works he left to posterity were 779 anatomical drawings and sketches. These illustrations, usually made beside the dissected subject, reveal an exacting acquaintance with muscular anatomy. These studies were often accompanied by annonations on physiology. In most respects the accuracy of pictorial representation was much greater for artists than anatomists [2].

Leonardo's work on anatomy falls into two distinct periods. His earlier drawings were made about 1487 to 1493, mostly in Florence and in Milan. They show his preoccupation with the structure of the skull and the eye, which he called the "*window of the soul.*" His later work began around 1506 and continued until his death in 1519 in France. This period encompassed studies on other organs, and was permeated with the recognition as to how mechanics relate to human physiology [3].

As a unit, the heart enabled Leonardo to integrate his observational skills, his understanding of mechanics, and his intutive grasp of fluid dynamics. He made several important discoveries that carried him to the threshold of recognition of the true pathway of the circulation.

Leonardo looked upon the heart as a "*vessel made of thick muscle kept alive and nourished by artery and vein as other muscles are*" with "*pre-eminent power over the other muscles*" that "*moves itself and does not stop if not forever*". In addition to observations and experiments on the hearts of larger mammals, he personally performed 30 human dissections, becoming the first to recognize many of the heart's individual features [4].

Describing the structure of the heart, Leonardo recognized not only the right and left ventricle (lower ventricles) but also the atria (upper ventricles), and he coined the term describing atrial appendages as ears (auricula). His drawings also properly show the pericardial sac (capsula), the endocardium, the shape and structure of the atrioventricular valves, and the moderator band (band of Leonardo) [5].

The three-cusped valves of the heart were seen by Leonardo as a perfect example of mathematical necessity in the working of nature. As blood was forced through the valve, eddies in the sinuses curved back into the cusps of the valve (Fig. 1).

When the flow ceased, these eddies opened the cusps against one another to form a perfect seal, preventing reflux. Two cusps would not allow a sufficient aperture for flux of the blood; four cusps would be too weak in closure. Three was the optimum number, and that is what nature had provided [6]. These observations have recieved support by Henderson and Johnson [7] in modern times. Leonardo may have realized that the atrioventricular, aortic, and pulmonary valves lay in the same plane (Fig. 2).

As has been demonstrated by Clark and others [8] although the leaflets are the most dynamic

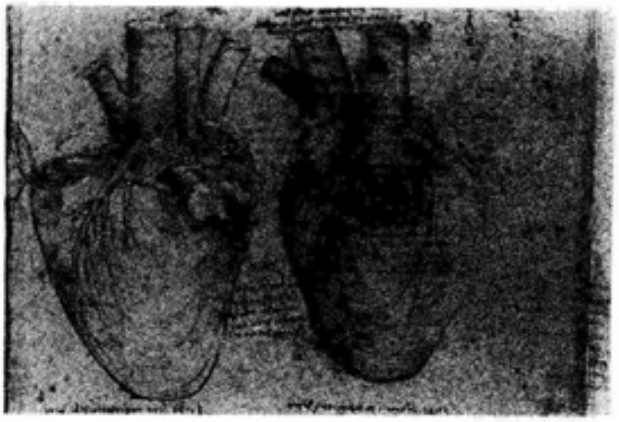

Figure 2. The heart: details of pulmonary valve and coronary arteries.

Leonardo wrote of the chordae tendineae, "*Nature has made the chords on the back side of the fleshly membrane of the three gates with which the gateway of the right ventricle is shot; and she was not made them on the front because these cusps feel more strain when (the ventricles) draw the blood in than when they push it out*" (Fig. 3).

Figure 1. The three-cusped valves: detail of anatomy.

Figure 3. The mechanism of chordae tendineae.

parts of the heart valves, the motion of other associated structures and the expention of the entire valve complex also play an important role [9-12]. Leonardo correctly placed the papillary muscles between cusps with chordae, but incorrectly described the function of the papillary muscles [6].

The coronary arteries were correctly illustrated. So, too, were the great vein and coronary sinus (Fig. 2). In addition, Leonardo apparently successfully determined that the apex of the heart comprised the left ventricle. Leonardo has accurately demonstrated the difference in cross-sectional thickness of the right ventricle as compared to the left ventricle [13].

Leonardo was able to deduce not only that the arterial pulse wave was synchronous with, but also that it was generated by, the contraction of the ventricles. Among the most amazing of Leonardo's anatomical observations were his studies of the function of the aortic valve, the significance of the sinuses of Valsalva, and the pattern of blood flow entering the thoracic aorta. Leonardo not only rendered the first functional description of the left ventricular outflow tract, the mechanism of aortic valve closure, and presented the most recently rediscovered pattern of blood flow through the aortic valve and, as incredible as it appears, he also designed the first duplicator, created the first bioprosthetic valve, and rendered the first design for an artificial heart valve [3]. In a brilliant investigation of the function of the valves, he constructed a glass model of the aortic valve and sinuses of Valsalva by taking a cast from ox's heart (Fig. 4).

Had he followed his mechanistic instincts, it is hard to see how the discovery of the circulation could have eluded him. But Leonardo was dogged by preconceptions derived from written authority, and he never discarded the ancient views that the arteries conveyed "*vital spirit*", that the veins nourished, and that the two systems were independent. The pulmonary system existed simply to refresh the blood and to prevent the heart from overheating; he even accepted the doctrine of a perforated interventricular septum, despite not being able to see any pores, finally deciding they were too small to

Figure 4. Three cusped valves and sinuses of the heart.

be visible [14]. It is so difficult to understand how Leonardo could so accurately comprehend heart contraction, the valves of the heart, as well as their function in the prevention of reflux, not glimpse circulation. Had he continued to question Galen and Aristotle, as well as to experiment, circulation may have been completely understood before Harvey in 1628.

Leonardo was indeed the artist who in the pre-Harveyan era got closest to discovering the circulation of the blood. After his death his drawings remained hidden for a century and therefore his brilliant observations left little impact in his own time and provided little stimulus when it could have accomplished the most. It was very likely that if a papal decree had not barred him from autopsies during his final years and if he had lived a few years longer, it would have been Leonardo who described the circulation of the blood and not

Harvey a hundred years later [15].

Although it is questionable that he ever thought of himself as an anatomist, his investigations went far beyond the point of artistic usefulness and one may properly suppose that Leonardo regarded his studies in anatomy as a separate discipline rather than auxiliary to his activity as an artist.

At the end of his life, reflecting on his achievements in anatomy, he wrote this to his novies:

"But though possessed of an interest in subject you may perhaps be deterred by natural repugnance or if it does not restrain you then perhaps by the feat of passing the night hours in the company of corpses, quartered and flayed, and horrible to behold. And if this does not deter you, then perhaps you may lack the skill in drawing essential for such representations, and even if you possess this skill, it may not be combined with knowledge of perspective, while it is not combined you may not possess the methods of geometrical demonstration, or the methods of estimating the forces and power of the muscles; or you perhaps may be found wanting ofpatience though you will not be diligent. Concerning which things, whether or not they have all notbeen found in me, the hundred and twenty folios I have composed will give their verdict, yes or no. In these I have not been hindred either by avarice or negligence, but only by want of the time. Farewell."

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