OPINION ARTICLE

The helical heart and its implication on the resulting spatial anatomic arrangement of its chambers

The helical heart and its implication on the resulting spatial anatomic arrangement of its chambers

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INTRODUCTION

Simply observing the heart inside the mediastinum reveals its helicoidal shape. Therefore, the heart chambers should be properly named relative to their three-dimensional (3D) oriented location.

The classic nomenclature refers to the chambers as right and left atria, and right and left ventricles. These spatial references fail to provide the actual location of the chambers and confound arrangement of the heart helical structure used for heart torsion (ejection) and detorsion (suction) movements. (1-5)

Spatial anatomic location When observing the heart naturally placed inside the mediastinum (Figure 1), it is easy to see the right atrium in this spatial topography. The other chambers have been wrongly named based on their 3D arrangement. The right ventricle has an anterior-right position, leaving scarcely any room for the so-called left ventricle, slightly located to the left when displaced by the anterior-right ventricle with a levorotatory position, but mainly in a posterior position throughout. Therefore, it should be called the posterior-left ventricle. The left atrium is even more markedly rotated backwards, and it can be found behind the ascending aorta with the transverse pericardial sinus separating them, hardly emerging the end of the appendage to the left (Figure 1). The most accurate name would be posterior atrium. This provides a clear understanding of the levorotatory position of the heart in its helical alignment.

Thus, there is a need to find a consistent nomenclature for the heart chambers based on the observed 3D arrangement. According to their spatial location, they should be called the right atrium, the anterior-right ventricle, the posterior-left ventricle, and the posterior atrium.

The ventricular chambers of this anatomical and functional helix are made up of two bands referred to as descending and ascending bands. (6) The former includes the right, left and descending segments, while the latter involves the remaining ascending segment (Figure 2). Therefore, the myocardial muscular structure has two spiral turns, with the initial and terminal ends inserted into a nucleus with an osseous, chondroid or tendinous structure that depends on the different species of animals and humans examined. This is called the cardiac fulcrum (Figure 2). (7) This insertion is the only noticeable site where myocardial fibers origin and end.

The insertion site called cardiac fulcrum is close to the tricuspid valve (right), the aorta (upper), and the pulmonary-tricuspid cord (anterior). To find it, we need to shift the pulmonary artery and the right segment to the left of the observer, revealing the aortic root. This also exposes the fulcrum as a supplementary element between the aorta and the myocardium, equidistant from both trigones, underneath the origin of the right coronary artery and detached from the aortic continuity.

This is not just a question of semantics but evidences the primitive tube rotation in the heart loop formation. Figure 1 shows the veins in the circulatory system coiled over the arteries. This happens because the pulmonary artery enables rotation by holding the aorta. It is on a left anterior position in relation to the aorta and is part of the levorotatory movement of the right ventricle to this side, to such an extent that the latter ceases to be strictly right positioned and becomes mainly anterior. The aorta serves as the axis for the spatial rotation of the heart chambers, leading to a helical heart.

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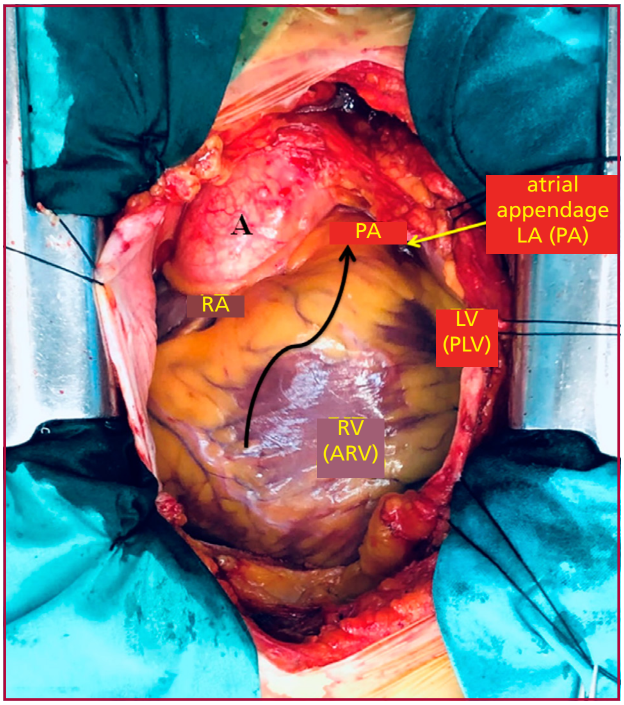

Fig. 1. Image of an in-situ human heart of a patient before surgery. The proposed nomenclature is between brackets. A: aorta; LA (PA): left atrium (posterior atrium); LV (PLV): left ventricle (posterior-left ventricle); PA: pulmonary artery, RA: right atrium; RV (ARV): right ventricle (anterior-right ventricle). The black arrow shows the direction of the levorotatory helical torsion in the venous circuit around the arterial circuit.

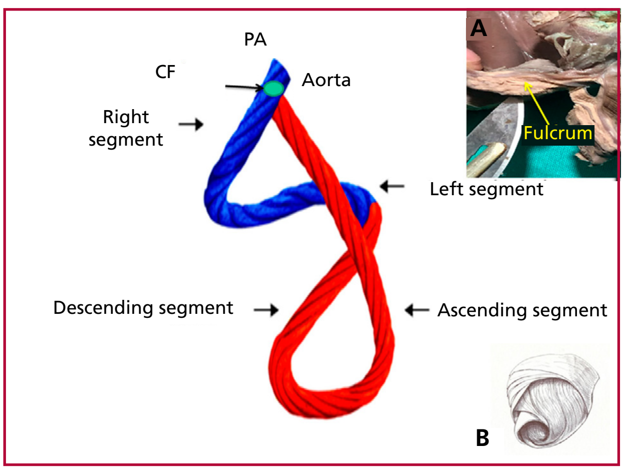

Fig. 2. Position of the cardiac fulcrum in the continuous myocardium (cord model). CF: cardiac fulcrum; PA: pulmonary artery.

Phylogeny

The worms (annelids, Nemertea) circulatory system is a closed one, with two capillary beds (pulmonary and systemic), and two semicircles: arterial and venous. In this single circulation system, blood is pumped through peristalsis (expression and suction) in the absence of heart beating (Figure 3A).

Evolution into fish shows emergence of a primitive heart in the venous semicircle, with three expansions called venous sinus, atrium, and ventricle, located in a successive manner. While the circuit continues to be a single one, there is a pumping chamber (ventricle) that can increase intravascular pressures (Figure 3B). The next biological stage, i.e., amphibians and reptiles, has much more prominent changes. This evolutionary phase involves two circuits, a systemic and a respiratory circuit, whereas the heart has two atria and one ventricle, the latter resulting from an incipient loop in the arterial circuit. (8,9)

Torsion of the circulatory tube over itself, on one segment of the arterial semicircle (systemic circuit), is an essential step in the evolutionary development of these species (Figure 3C). Future ventricular chambers will arise from this loop, a morphology that is better understood when unfolding the myocardial band forming the ventricles. (4)

The development of the circulatory system of birds and mammals shows two atria and two ventricles. The loop in amphibians and reptiles is completed in the arterial semicircle forming a helical myocardial structure. On the loop of the primitive arterial tube in this segment, the effect caused by a longitudinal cleft creates canals that will later become ventricles (Figure 3D). The origins of the pulmonary artery and the aorta in mammals show evidence relative to that evolutionary cleft in the arterial circuit. (10) This is the space between the trigones in the posterior part of the aorta, where the posterior mitral valve is embedded. In the pulmonary artery, this is the division in the para-endocardial segment (the right segment,

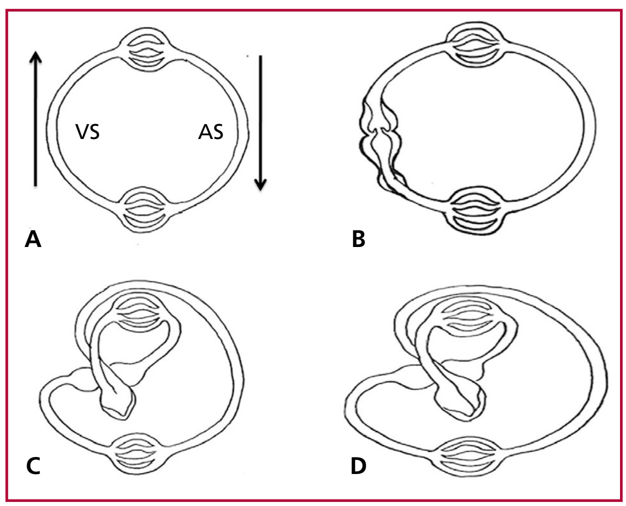

Fig. 3. Circulatory system phylogeny.
AS: arterial segment; VS: venous segment.
The arrows show the direction of circulation.
A: worms. **B:** fish. The three expansions of the venous segment (venous sinus, atrium, and ventricle). **C:** amphibians and reptiles. The arterial segment is the origin of the loop leading to both ventricles and permanently finished in **D:** birds and mammals

where the myocardium originates) into two bands: pulmonary and septal. Both are shaped as an inverted V, revealing the beginning of the gap leading to the continuous myocardium. (9)

This process provides two chambers that pump blood from the loop outlet to the systemic bed with enough energy and at high speed (up to 200 cm/s in humans) across the left ventricle, and to the pulmonary artery across the right ventricle at pressures 20% higher than the systemic circuit. This evolutionary trick led to the development of a chamber capable of pumping the intravascular flow in the segment of the arterial circuit fast enough for the flow to continue across the body. Therefore, in mammals, ventricles come from the incipient twisting of the arterial segment equivalent to the arterial circuit in amphibians and reptiles.

If we go back to the primary stage in the evolution of the circulatory system, phylogenetic milestones for different species become apparent. The atria belong to the venous segment and the ventricles belong to the arterial segment. A subsequent more pronounced bend of the arterial segment creates contact between the atria and their corresponding ventricles. In this way, the horizontal arrangement of both atria (chambers proceeding from the venous semicircle) is attached to the ventricular constituent (arterial semicircle).

When ontogeny recapitulates phylogeny (11), heart tube bending can be observed in the human embryo, which first becomes lateral and then twists as a spiral, as a reminisce of the evolutionary process (Figure 4). Consequently, the bulboventricular loop curves forward and to the right. This movement is possible

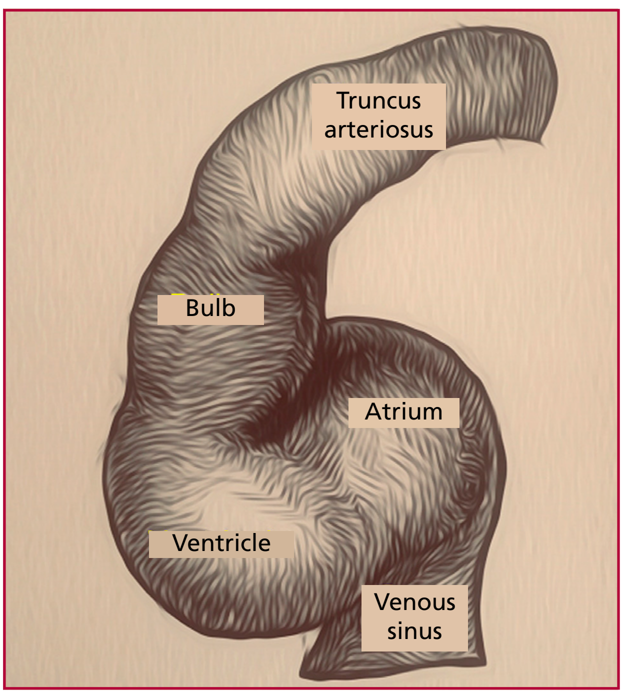

Fig. 4. Heart tube bending in the human embryo.

when the dorsal mesocardium disappears leaving the heart fully pendular in the chest but anchored by the cardiac fulcrum. (7) As with every muscle, this is the point of support that provides the muscular leverage, which enables torsion and detorsion throughout the cardiac cycle.

CONCLUSIONS

The concept of a linear circulatory path precluded true understanding of the helical anatomic structure. While this sequential structure defines the heart chambers where blood flows, it is the helical myocardium that determines the dynamics. (12) Historically, blood flow across atrial and ventricular chambers has been understood in a way that differs from structure and function. Myocardial torsion creates speed and the resulting intraventricular pressure with less energy expenditure and more effectively. Linear pumping across a circulatory tube would fail to cause this effect. Ultimately, myocardial dynamics propels circulation, and it is also worth pointing out the potential consequences of biomechanical forces created by the helical movement of the intracardiac flow on cardiac morphogenesis modulation during the embryonal life. (13,14)

This, supported by the anatomy and closely related to cardiac function, leads to a myocardial helical alignment that is very different from the concept of atrial-ventricular unity that precluded proper understanding of the heart physiology. The horizontal arrangement of the atria (chambers relying on the venous semicircle) became attached to the ventricular muscular constituent (chambers relying on the arterial semicircle) where suction and ejection caused by the blood flow movement emerge, according to the stages in the cardiac cycle.

Conflicts of interest

None declared.

(See authors' conflict of interests forms on the web/Additional material.)

Ethical considerations

Not applicable.

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