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Research Article

Why Is The Heart Helical?

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Abstract

Introduction: The myocardium is a continuous, integral, longitudinal muscle. When folded, it forms a helix, aligning the ventricles contiguously and interdependently througha septum, allowing for the torsion/detorsion mechanics. This study explores the fundamental twists of the continuous myocardium that allow it to achieve its helical position.

Materials and Methods: Eighty-three bovine, human, porcine, and anuran hearts were used. They were subjected to myocardial unfolding. Histology was performed with hematoxylin-eosin staining, Masson's trichrome technique, and 4-micron sections.

Results: The continuous myocardium, which forms a helix, produces three twists along its length. The first is located horizontally in the basal loop, forming the free wall of the right ventricle. The second twist occurs between the left segment and the descending segment. Its location is referenced by the posterior papillary muscle. It is the sum of a 180-degree torque in the linearity of the myocardium, similar to a Möbius strip, together with a sudden twist that directs it downward toward the cardiac apex at a 90-degree angle. The third, located between the descending segment and the ascending segment, is the apical twist, with the anterior papillary muscle as an anatomical reference. This involves a change in the direction of the myocardium: the downward orientation of the myocardium becomes ascending.

Conclusions: The three twists that occur in the continuous myocardium constitute a hallmark of the helical heart. They allow the ventricles to be aligned contiguously, forming the septum by directing the descending segment (continuity of the left segment) in parallel and contiguous with the ascending segment, which arises from the continuity of the descending segment when it changes direction at the apex, oriented toward the cardiac base. In this way, the anisotropic properties of its fibers determine that stimulation, when passing between these segments, can produce a helical movement with opposing forces, leading to myocardial torsion-detorsion.

Keywords : *Continuous myocardium-Helical heart-Cardiac dissection*

INTRODUCTION

The heart is a mythical organ, a source of passion and eternal return. Recent anatomical and technological research has shown that its globular structure conceals a continuous myocardium folded into a spatial double helix (Figure 1), whose origin and end are located in a support called the cardiac fulcrum. This is where the myocardial fibers originate and end after traveling along the helical path that delimits both ventricular cavities (**Figure 1**).(1)

This anatomical-functional architecture is made up of two bands called the descending and ascending bands. The first includes the right, left, and descending segments; while the second is made up of the remaining segment, the ascending one. The figure-eight image created by this path allows us to distinguish two loops called the basal and apical (**Figure 1**).

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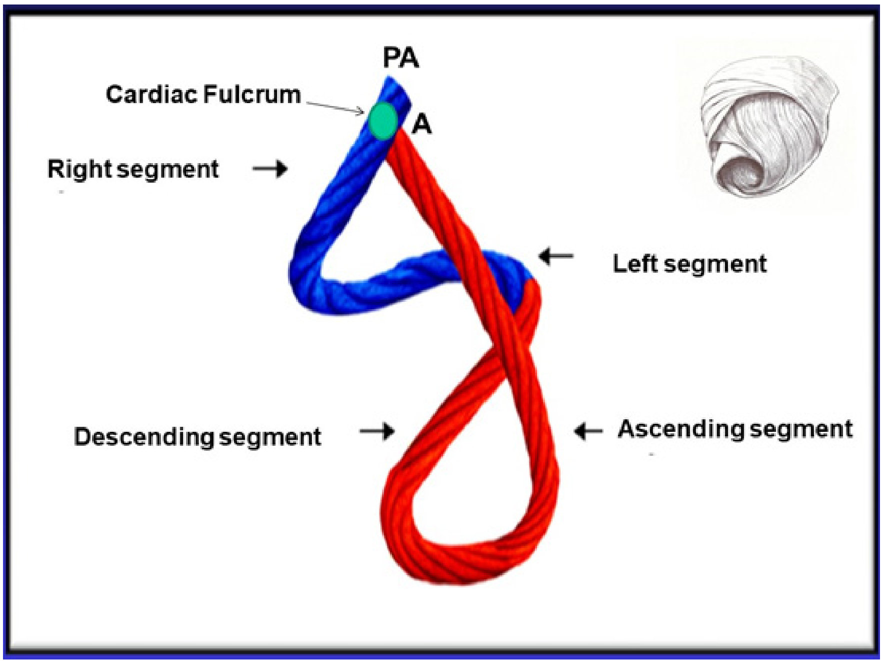

Figure 1. Cord model of the helical myocardium that simplifies the spatial structure. It illustrates the different segments forming this structure. In blue: basal loop. In red: apical loop. PA: position of the pulmonary artery; A: position of the aorta. The right inset shows the three-dimensional helical arrangement of the continuous myocardium.

The contraction and detraction of the fibers of the continuous myocardium, whose ends must rest on a support, the cardiac fulcrum, to have a mechanical effect, would not be effective without its existence, which ensures the cardiac system's functionality (2), allowing the forces to be distributed adequately, to exert not only a support effect but also a stabilization of the movements, since these are sequential and asymmetrical. For this mechanism to be subjected to tractions on a magnitude of about one hundred thousand cardiac cycles daily, the fulcrum must meet certain conditions: a) stability; b) resistance; c) elasticity and d) plasticity. When subjected to loads, these faculties allow the fulcrum to reach a certain level of stress, modify its spatial location with the variation of the same and then recover when they are removed (**Figures 2 and 3**).

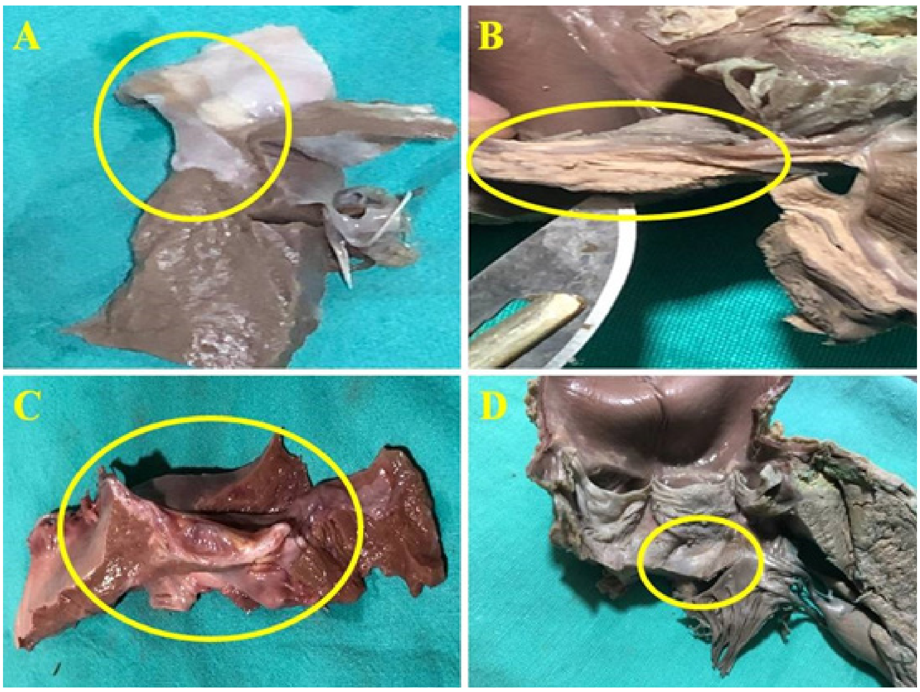

Figure 2. Cardiac fulcrum (yellow circle) in porcine (A); adult human (B and D); bovine (C).

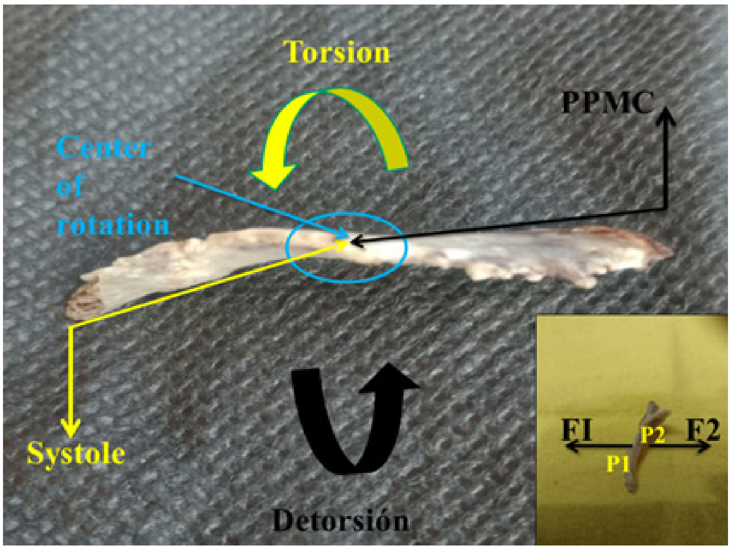

Figure 3. The yellow arrows show the orientation of the cardiac fulcrum movements during systole; the black arrows show the suction (protodiastolic phase of myocardial contraction -PPMC). The box shows that if only one force is applied to the fulcrum, it would move; on the contrary, if a force (F2) equal and opposite to F1 is applied at the insertion point P2, opposite end to P1, the fulcrum does not destabilize.

The unfolded continuous myocardium constitutes a set of muscle fibers, flattened laterally and extended longitudinally. Forming two spirals, it defines a helix that delimits the two ventricles and determines their functionality. This topographical structure is based on the evolutionary process that occurs from the primitive circulatory tube of annelids to mammals, in whose arterial semicircle a loop develops, causing it to coil around itself to duplicate and form the ventricles.(1) With folding, the myocardium changes from a longitudinal muscle to a helix, aligning the ventricles contiguously and interdependently through a septum, allowing for the torsion/ detorsion mechanics. Therefore, this research analyzed the fundamental turns of the myocardium that allow it to fold into its definitive helical position. Once the helix is formed, it is confirmed that the beginning and end of the continuous myocardium converge at a single point, the cardiac fulcrum (**Figure 1**).

MATERIAL AND METHODS

Eighty-three hearts from the morgue, slaughterhouses and breeding farms (for anurans) were used: a) 53 two-year-old cattle weighing between 1300 and 1900 g (average 1650 g); b) 17 humans (three at 8, 16 and 23 weeks of gestation respectively; four infants at 30 days, 36 days, 10 weeks and 27 weeks; one 4-year-old child; one 10-year-old child and eight adults with an average weight of 300 g); c) 3 porcine hearts (average 400 g); d) 10 anurans. Histology was performed with hematoxylin-eosin, Masson's trichrome staining technique and four-micron sections. 10% formalin was used as buffer.

Dissection technique. The heart to be dissected was boiled in water with acetic acid (15 cc per liter) for two hours. This step allowed the myocardium to be free of fat deposits, making dissection easier and tidier. Then the aorta and pulmonary artery were cut about three centimeters from their origin separating the attachment between them to subsequently perform a longitudinal incision at the level of the interventricular sulcus on the superficial fibers extending transversally along the anterior wall of the ventricles (interband or aberrant fibers) (3). Between the atria and the ventricles there is only connective tissue, allowing the easy separation of these chambers due to the denaturation produced by heat. This confirmation agrees with Claudius Galen's theory in the II century AD stating that the atria can be detached from the ventricles without any incision, by simply separating them from their respective ventricles. In the evolutionary process, the horizontal arrangement of the atria (dependence chambers of the venous semicircle) was attached to the ventricular muscle component (dependence chambers of the arterial semicircle), so their origins were different. Thus, the single atrium in fish became the right atrium in mammals, while the single ventricle became the left atrium. Both atria then represent strategic vestiges of the venous segment in the primitive circulatory duct of fishes.

At the beginning of the unfolding process a key factor must be considered, since any attempt of not respecting the dissection axes where the myocardium folds, ruptures the myocardial mass. This situation, without knowledge of the helical cardiac structure, had already been envisioned by Andreas Vesalius in his 1543 publication "De Humanis Corporis Fabrica". Accordingly, Francisco Torrent Guasp used a balsa wood spatula to avoid slits in the myocardial mass.

The key maneuver to unfold the myocardium consists in entering into the anterior interventricular sulcus with a blunt instrument, leaving on the left side of the operator the end of the myocardium corresponding to the pulmonary artery and its continuity with the right ventricular free wall (right segment). Next, traction is applied towards the same left side, completely releasing the pulmonary artery from the rest of the myocardium. This myocardial dissection reveals the cardiac fulcrum below and in front of the aorta, in a separate location from the right trigone and in an inferior plane to the origin of the right coronary artery, without continuity with the aortic valve and inserted as a complementary element between the aorta and the myocardium.This structure, point of attachment of the origin and end of the cardiac muscle, constitutes the insertion of the myocardium in a manner analogous to a skeletal muscle.(2)

It should be understood that as the myocardium is unfolded, separating the pulmonary artery and the pulmonary-tricuspid cord (anterior) from the ascending segment (posterior), the view of the anatomical homogeneous and functional integrity of the heart is lost. This bond between the origin and end of the cardiac muscle in the cardiac fulcrum constitutes a meeting point between the right segment and the ascending segment, origin and end of the myocardium. Thus, both ends are situated in the same point, with the origin of the myocardial fibers placed anteriorly to those of its end. .

The progression of the myocardial dissection implies finding the whole extension of the right segment, the beginning of the left segment, and in the posterior margin of the right ventricular chamber the dihedral angle formed by the interventricular septum and the free wall of the right ventricle (right segment) (**Figures 4 A and B**). The next step (the most delicate one) consists in entering the aforementioned dihedral angle between the right ventricular and intraseptal fibers. This separation of the right ventricle allows entering into the ventral part of the septum (**Figure 4 C**). Then, the dorsal part of the septum is dissected between the posterior septal band (right ventricle) and the descending segment to detach and separate the aorta.(3)

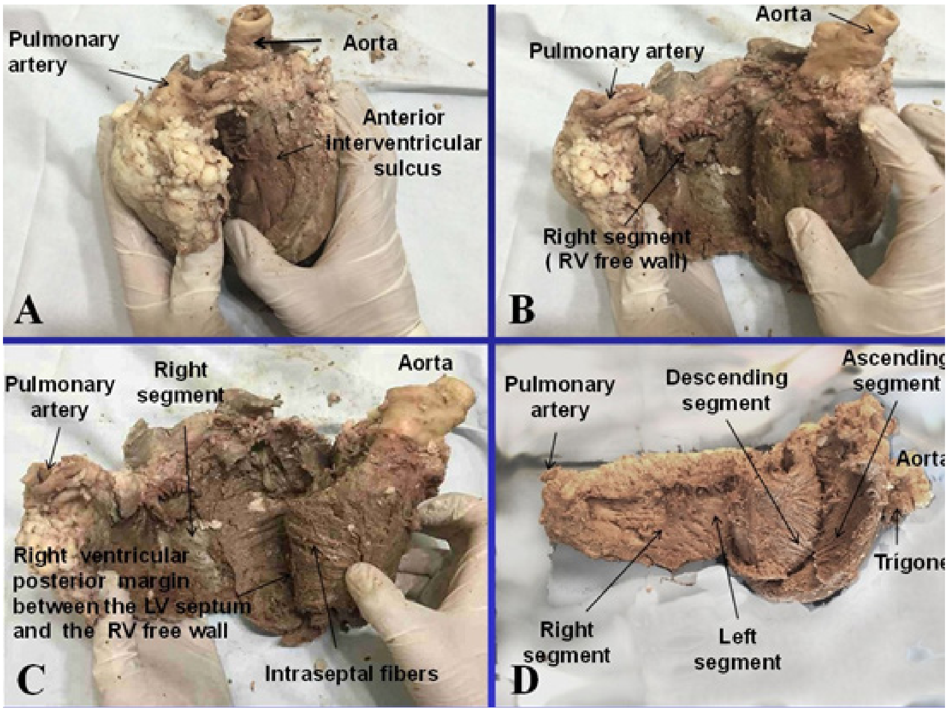

Figure 4. Unfolding of the continuous myocardium.

Finally, the pathways of the muscle planes belonging to the descending segment are separated in a blunt manner from those of the ascending segment which leads to the cardiac fulcrum contiguous to the aorta to the right of the operator, allowing by rotating its ends to extend and align the continuous myocardium in all its length (**Figure 4 D**). Being able to unfold the myocardium with a similar thickness in all its extension proves that it is unique and continuous and not a heuristic construction (**Figure 5**).

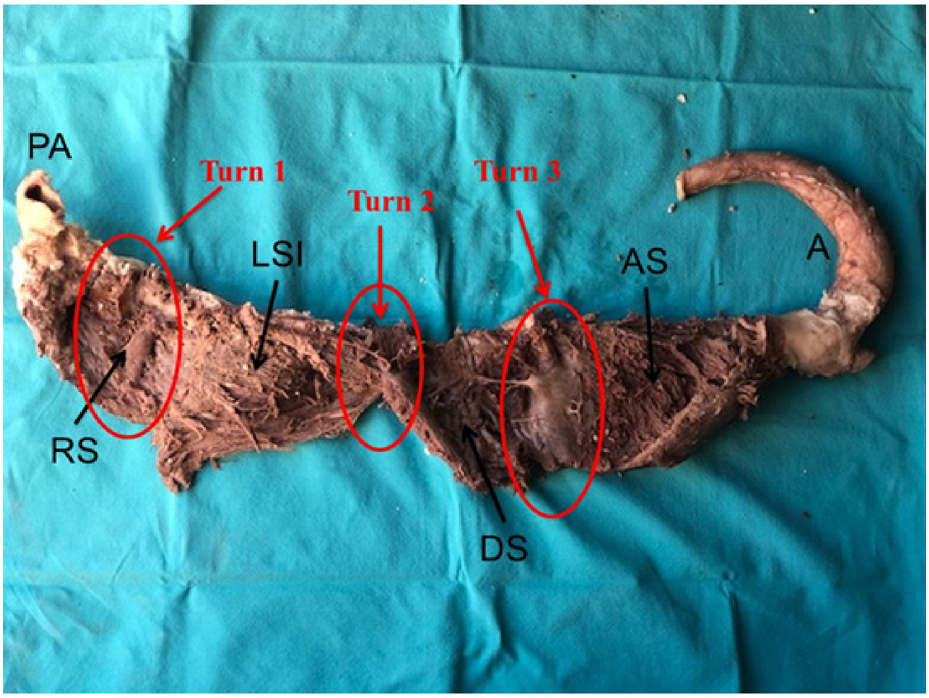

Figure 5. Myocardium unfolded in all its extensión. PA: pulmonary artery; RS: right segment; LS: left segment: DS: descending segment; AS: ascending segment; A: aorta. The red circles highlight the sites of the three turn of the continuom myocardium to transform into a hélix.

RESULTS

In dissections, we find that when the continuous myocardium folds to form a helix, it must produce three turns in its extension. The chord model used to illustrate the helical heart accurately indicates these three turns (**Figure 6**).

1. The first is located in the basal loop on the right border of the heart. It is a slow rotation determined by the right segment. It runs from front to back in a horizontal position, forming the free wall of the right ventricle.
2. The second twist occurs between the left segment and the descending segment, constituting a fundamental anatomical fact in the formation of the interventricular septum. Its location is referenced by the posterior papillary muscle. Its characteristics are different from the other two, as it is the sum of a 180-degree torque in the linearity of the myocardium, similar to a Möbius strip, together with a sudden torsion that directs it downward toward the cardiac apex at a 90-degree angle. This turn is resistant to attempts to restore manually the longitudinal structure of the myocardium. Thus, when attempting to unfold it by reversing the turn, considerable force must be exerted to achieve this goal.
3. The third turn, located between the descending segment and the ascending segment, is the apical turn, with the anterior papillary muscle as its anatomical reference. The apical turn involves a change in the direction of the myocardium so that the downward orientation of the myocardium becomes ascending, that is, from the tip to the base, opposite to what it had after the second turn (base-apex). As a result of this change, the apex is delimited (**Figure 7**).

The anterior and posterior papillary muscles of the left ventricle, strategically located at the beginning of the second and third turns, are determining that they not only have the function of opening the mitral valve, but they are tensors of the helical myocardial architecture, avoiding the sphericity of the ventricle. This situation is evidenced in postoperative ventricular dysfunction after mitral valve replacement, since by suppressing the function of the papillary muscles by section of the tendineous chords, there is myocardial deformation with alterations in contractility.(4) This has motivated that the chords of the papillary muscles are not sacrificed but tied to the mitral annulus in order to preserve the tensors of the descending and ascending cardiac segments.

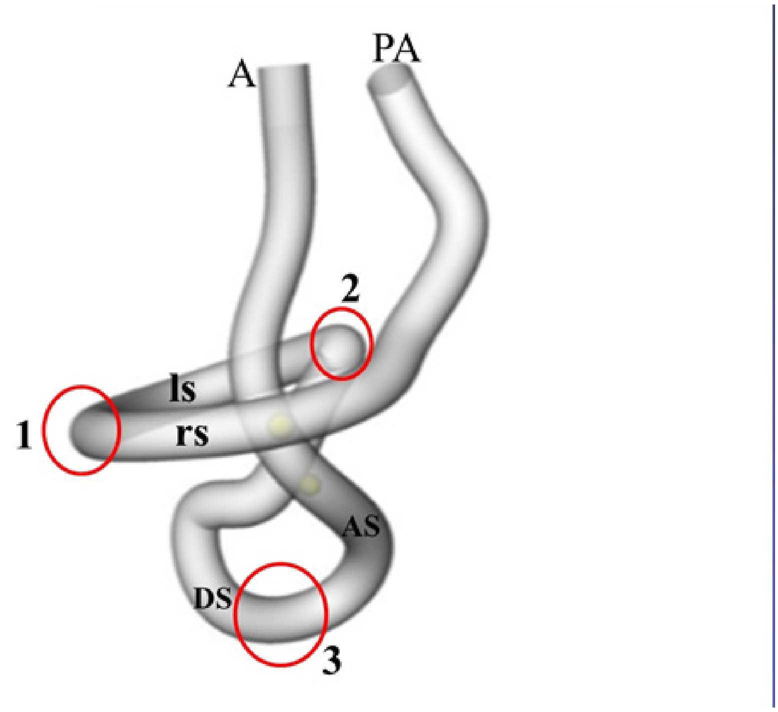

Figure 6. Helical myocardium in the string model that simplifies the spatial structure with the three turns. The different segments that compose it are shown. sd: right segment; si: left segment; SD: descending segment; SA: ascending segment. AP: location of the pulmonary artery; A: location of the aorta. The three turns (red circles) that determine that the continuous myocardium becomes helical are located, with the consequent alignment of the ventricles to be able to exercise their torsion/detorsion function

This particularity of the three turns in the continuous myocardium allows it to acquire a helical conformation, which gives the ventricles adequate capacity and aligns them in contiguity, forming the interventricular septum at that limit, which is essential for the mechanical function of cardiac torsion/detorsion.

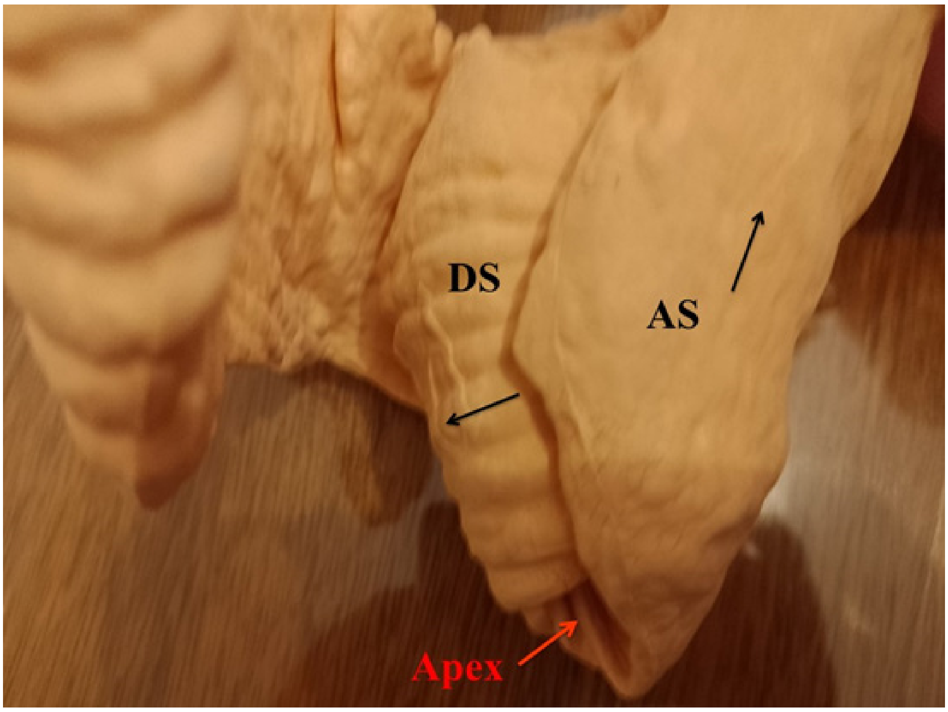

Figure 7. This model shows the apical turn and the different orientations of the fibers in the descending and ascending segments (arrows), which shows the anisotropic nature in order to achieve the torsion-detorsion necessary for the cardiac cycle. Ref. SD: descending segment; SA: ascending segment.

Continuous myocardial topography. In its course, the myocardium adopts a helical configuration that defines the two ventricular chambers.(5) The myocardial helix has its initial and terminal ends inserted into a structure whose histology is bony, chondroid, or tendinous, according to the different animal and human specimens studied in our research. We have called it the cardiac fulcrum, and it supports the myocardium (2). We found proof of this when we directed the histological analysis to the point where the myocardium inserts into the cardiac fulcrum. This myocardial attachment, which we can symbolize as "ivy to stone," was found in all the hearts analyzed. This attachment to the fulcrum structure was integrated into a myocardiocyte-matrix unit, whether bony, cartilaginous, or tendinous, according to previous studies (**Figure 8**).

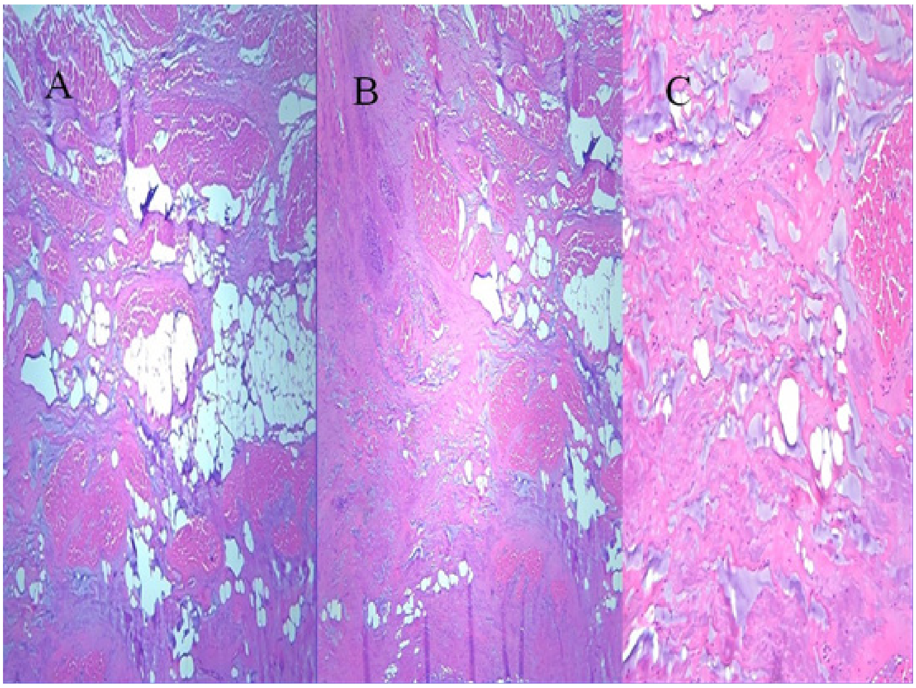

Figure 8. Adult human heart. A: Ascending segment of the continuous myocardium before entering the cardiac fulcrum. Scant prechondroid tissue. Adipose tissue is observed. B: The same segment entering the fulcrum. Still scant prechondroid tissue. C: Ascending segment inside the fulcrum. The fibers are already surrounded by prechondroid stroma. H&E technique (15x).

The first turn occurs in the basal loop, which allows the right ventricle to be delimited by the right segment. This loop (right and left segments), from its insertion into the cardiac fulcrum, extends to the second turn, which is the sum of a 180° torque and a 90° torsion in the longitudinal axis of the continuous myocardium. This turn occurs when the left segment, after this bias, transforms into a descending segment at the level of the posterior papillary muscle, in a sudden and fundamental change of direction. (**Figures 9 to 11**).

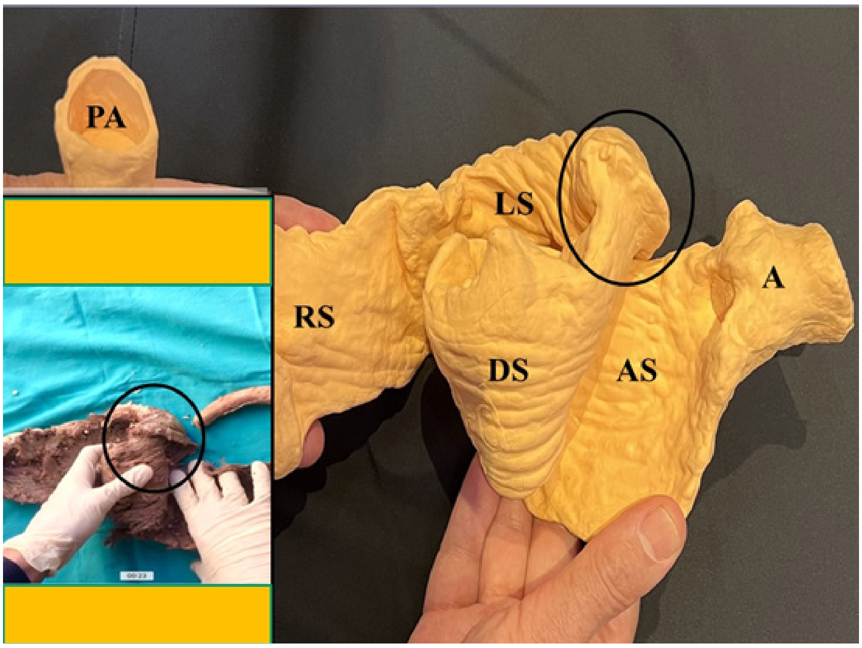

Figure 9. A: Model of a partially folded helical heart. The circle shows the site of the second continuous myocardial turn

(torque of 180° and torsion of 90°). RS: right segment; LS: left segment. DS: descending segment. AS: ascending segment. AP: pulmonary artery. A: Aorta. The box shows the second turn (torque and torsion) in a bovine heart in the black circle.

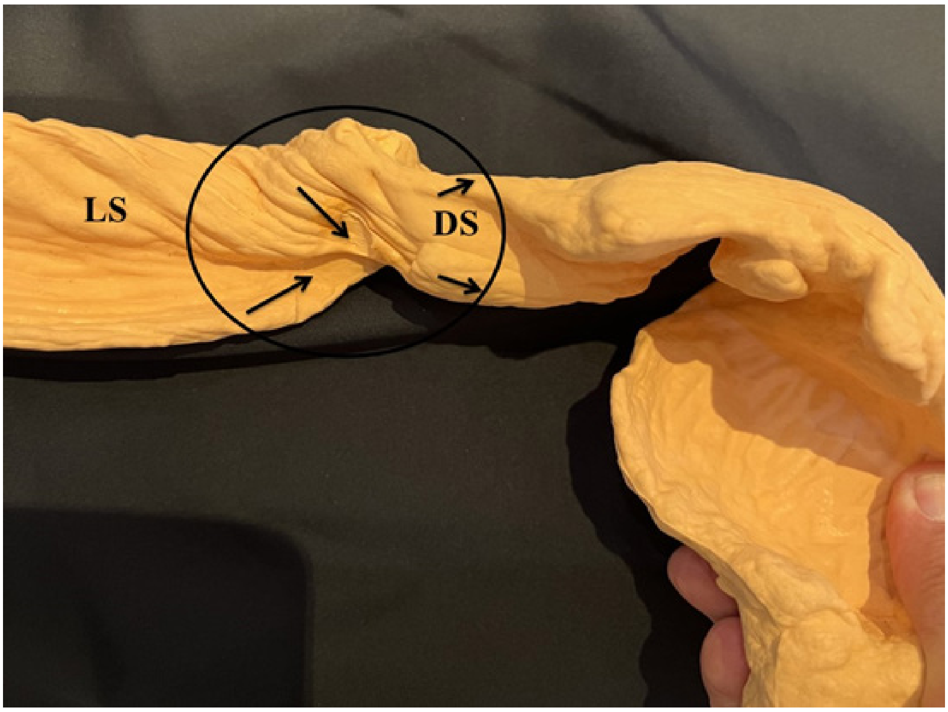

Figure 10. The myocardium represented in this model is unfolded in order to show the direction of the fibers. A significant force must be applied to detorque the band as it rotates and to unfold it. When folded, in its normal helical spatial situation, the segments overlap, acquiring the necessary homogeneity to exert their power. Ref. LS: left segment; DS: descending segment.

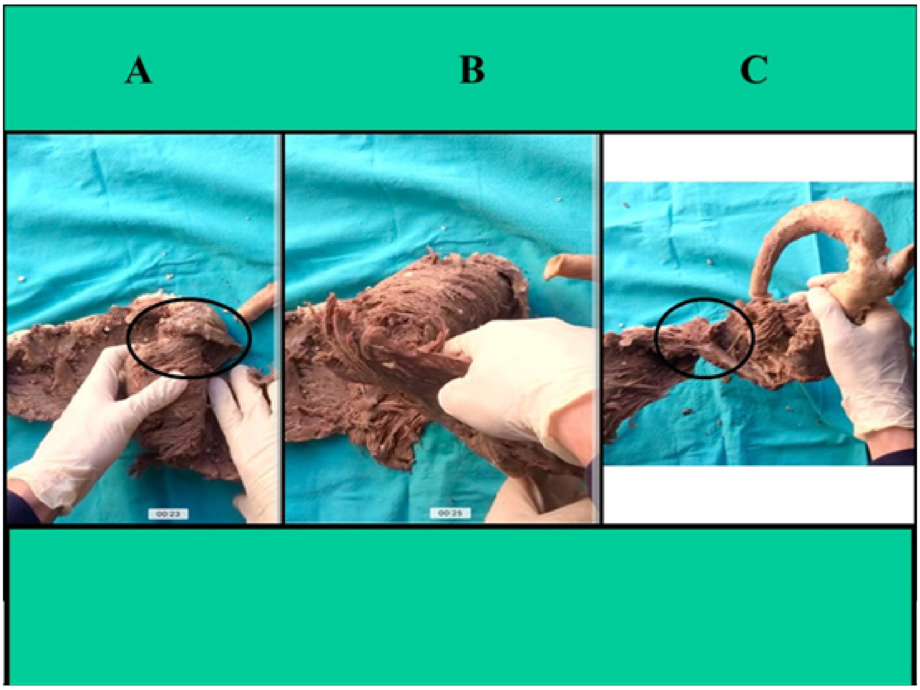

Figure 11. In A, the torsion is observed, in B, the unfolding, and in C, the torque, in the second turn of the myocardium.

The apical loop runs from this second turn to its termination at the cardiac fulcrum (aortic base). Each loop consists of two segments. The basal loop is made up of the right and left segments. Those belonging to the apical loop are called descending and ascending (Figure 1). In this loop, the change in direction between the two segments determines the third turn, the apical. In the integral arrangement of the loops, the basal loop embraces the apical loop, which determines that the right ventricular cavity appears as an open cleft in the thickness of the muscular mass that makes up both ventricles (inset in Figure 1).

Basal loop. The posterior interventricular sulcus presents a trough that outlines the limit between the right and left basal loop segments. The right segment constitutes the right ventricular free wall and surrounds externally the tricuspid valve orifice. The left segment situated in the left ventricular free wall defines the mitral valve orifice externally. The fibers run from the subepicardium to the subendocardium following a counterclockwise helical pathway (apical view of the diaphragmatic surface of the heart in the anatomical position).

Apical loop. The descending apical segment extends from the fold in the continuous myocardium to the apex. From this point it becomes the ascending segment that mainly ends below the base of the aorta in a structure to which the myocardial fibers attach and that we have called cardiac fulcrum. The anterior papillary muscle is a reference between both segments, which mainly constitute the interventricular septum. Similar to the basal loop, the fibers run from the subepicardium to the subendocardium, but in this case following a helical clockwise pathway (apical view of the diaphragmatic surface of the heart in the anatomical position). These concepts indicate that the right ventricle is formed by a single loop (basal) and the left ventricle by two loops (basal and apical). In addition, the right ventricular free wall is formed by a single segment (right segment), while the left ventricular free wall is essentially made up of two segments, with the ascending segment (external) overlapping the descending segment (internal). Regarding the left segment, it forms the posterior part of the left ventricle limiting the mitral orifice, and its lower portion is covered by the ascending segment.

DISCUSSION

The traditional anatomy of the heart considered that the muscle structure that formed the myocardium was homogeneous and compact (6,7). Based on this concept, it was usually described with an external and an internal surface limiting a solid and uniform muscle mass, which opened and closed en bloc in systole and diastole, respectively. Andreas Vesalius in his work "De Humanis Corporis Fabrica" (1543), referred to the difficulty in discerning the layers that form the myocardium. He literally expressed: "Whichever way you perform a dissection of the heart meat, either raw or cooked..., you can hardly remove a portion with only one type of fiber, because they have multiple and different pathways, mainly transversal". More than three centuries later, J.B. Pettigrew (1864) also referred to this situation: "Of the complexity of the arrangement I need not say more than Vesalius, Haller and De Blainville; all confessed their inability to unravel it" .(8).

This anatomical structure was related to what William Harvey stated in his great book "Exercitatio anatomica de motu cordis et sanguinis in animalibus "(1628) when he established that "the heart closes and opens like a fist" .(9) The validity of this principle never considered the analysis made a short time later, in 1669, by Richard Lower in his "Tractatus de corde: item motu et colore sanguini, et chyli in eum transitu", where he considered that the myocardium was composed of two spiraling muscles and that blood ejection was similar to the "wringing of a linen cloth to squeeze out the water".(10)

This last concept without modifications would be repeated sporadically by Sénac (1749) (11), Wolf (1792), Gerdy (12) and Weber (13). Later, MacCallum (1900) (14), Mall (1911) (15) and Lev (16) would return to what said Lower. Afterwards, Streeter (17), between 1966 and 1979, in light of the myocardial structure referred to him by Torrent Guasp (18), would get close to the current principles. Beyond these contributions, the power and prestige held by Harvey relegated an anatomo-functional certainty that has only been recently imposed mainly through anatomical, histological and electrophysiological studies, and the incorporation of echocardiography and. cardiac magnetic resonance images (19-23).

In light of current investigations, the classical structural concept does not justify cardiac mechanics; it is therefore essential to establish the true ventricular anatomy, because knowing the structure leads to understand its function. Historically, very little importance was attributed to the spatial arrangement of the muscle pathways that constitute the myocardium, although in 1923 R.F. Shaner reported that: "the myocardium is made up of two flattened muscles in the shape of an 8 ... These muscles twist in opposite direction during systole, emptying its content".(6).

Since 1970, Francisco Torrest Guasp (24) defines the anatomy of the heart adapted to physiological reality. In the town of Denia (Alicante, Spain) where he worked as a doctor, he demonstrated with his handcrafted anatomical research of multiple dissections of the hearts of different species, including humans, that the ventricular myocardium is made up of a set of muscle fibers coiled unto themselves resembling a rope (cord model), flattened laterally like a "band", a word he used to define the myocardium. This "band", by presenting two spiraling turns, describes a helix limiting the two ventricles and shaping their functionality. This topographic structure is supported by the evolutionary process taking place from the primitive circulatory duct of annelids to mammals, whose arterial semicircle forms a loop or fold that coils unto itself giving rise to the ventricular chambers.The lumen of the primary duct establishes a secondary communication between both adjacent chambers (ventricles) formed by the loop, assuming that where the interconnection takes place it must have cleaved all along to achieve this purpose. The three-dimensional perspective is essential to understand the interaction between anatomy and function, since if we seek to analyze the movement of myocardial fibers through their arrangement seen in two-dimensional histological sections, we will not reach any effective conclusion.

Concerning the development of ideas on the myocardial spatial configuration, MacIvear et al. (25,26) consider that the ventricular walls are formed by an intricate three-dimensional network of cardiomyocytes. This mesh model implies that the cardiomyocytes are arranged at radial and longitudinal angles. So far, leaving behind the classical conformation of the uniform myocardial anatomy, as analyzed above, two theories of its spatial structure had been established: that of a band (Torrent Guasp) and that of a mesh (MacIvear). Through our anatomo-functional research we consider that the terms band and mesh are not appropriate. The myocardium as a single muscle coiled as a helix, is not accurately represented by the word "band." This concept does not correspond to the etymology of the word or to a complete helical spatial structure of its pathway, where it is forced to superimpose the segments. Perhaps, this nomenclature has been unfortunate, limiting the real understanding of Torrent Guasp's works, since the word "band" is defined as an elongated strip that goes from end to end, which is identified from the surface on which it appears with well-defined margins and without constituting the integrity of the structure that supports it. It only represents a part of the structure, a situation that does not occur in the myocardium, since the muscle that makes it up is a whole, an integral piece.

We also found that the myocardium is not arranged as a mesh. This definition is not related with the functional anatomy of the heart (2, 27,28). The mesh concept was elaborated without assuming that the helical conformation of the myocardial continuity overlaps its segments to achieve its functional topography. There are criteria, such as the anatomical unfolding of the myocardium, that support the concept of myocardial sequence as a single, continuous, spiraling muscle with insertion at its ends. The same happens with echocardiography and cardiac magnetic resonance imaging demonstrating the opposite movements of the overlapping segments.

According to the above, we find that the spatial arrangement and rotational movement of the ventricular fibers, both at the base and apical region, correspond to a helical myocardium, resulting from the convergence between evolution, structure and function. However, this anatomy that allows unfolding the heart to form a continuous muscle was not considered with validity criteria by some academic groups, after its original description.

Given the criticism or indifference that unfolding the helical myocardium has raised, we believe that owing to lack of information on the anatomical dissection technique, we can currently obtain its confirmation through:

1) The anatomical and histological investigation of the heart.
2) The phylogenetic evolutionary concept.
3) New imaging procedures obtained with diffusion tensor cardiac magnetic resonance sequences.
4) Echocardiography.
5) Electrophysiological studies carried out with three-dimensional electroanatomic mapping (29).

Regarding the argued difficulty of myocardium dissection, which is more apparent than real (3), we must consider that since the myocardium originated as a loop in the arterial semicircle of amphibians and reptiles to adapt to the mechanical physiology of aerial life, the muscle bundles became firmly attached to their contact surfaces, hindering the necessary cleavage planes to achieve their anatomical dissection. The evolutionary goal was to obtain a hemodynamic structure with sufficient strength and energy to generate the blood volume suction and ejection to supply the whole body by facilitating torsion and detorsion of the cardiac muscle without losing its configuration. Thus, any attempt to dissect an anatomical segment from the rest of the myocardium must not deviate from the axes through which the orientation and the defined planes of the continuous helical arrangement pass. This impossibility, as previously cited, was observed by Andreas Vesalius in 1543. In conclusion, there are currently enough data to understand that the myocardium is a single, continuous, helical muscle subject insertion at its origin and end. This helical arrangement and the notable physiological characteristics of the myocardium correlate with its cardiac structure. This situation compels having a supporting point to fulfill the function of a suction-ejective pump with the size equivalent to a human fist and an average weight of 270 grams, which ejects 4-6 liters/minute at a speed of 200 cm/s, consuming only 10 watts, and working without interruption for 80 years without maintenance, and almost without noise. Its work is equivalent to the daily withdrawal of 1 ton of water 1 m deep with 50% mechanical efficiency (work/energy relationship) not achieved by man-made machines which only attain 30% efficacy. This efficiency allows ejecting 70% of left ventricular volume with only 12% shortening of its contractile unit, the sarcomere.(1)

Myocardial dissection reveals a structure with well-defined separation planes and a continuous helical arrangement of its segments, allowing the successive and concatenated physiological heart movements of narrowing, shortening-torsion, lengthening-detorsion and expansion, a consequence of the propagation of the electrical stimulus through its muscular pathways.

The myocardial fibers that make up the myocardium cannot be considered as absolutely independent entities within their defined space. Despite the intricacy of fiber bundles with polygonal shape, which receive and give out collateral fibers, a predominant pathway of central fibers is well defined, with sliding planes that together make up the helical myocardium. The concept that the myocardium constitutes a spiraling continuum of its fibers responding to the helical pattern of its muscle bundles should not be disregarded. This arrangement indicates the need of generating a mechanical work that dissipates little energy. Therefore, the fiber layers very gradually shift their orientation, with more or less acute angles, to avoid abrupt changes in the spatial organization that might waste the necessary work for cardiac function. The spectrum of fibers that is formed reduces the stress between them.

This situation that mimics a maze of fibers enables the left ventricular myocardium to act as a continuous transmission chain with the epicardial and endocardial fibers taking oblique directions, but with opposite sense, allowing reverse movements between them (figure 7). The access angle of the endocardial and epicardial plane is approximately 60 degrees in relation to transverse fibers. Fiber orientation determines function and thus the ejection fraction is 60% when the normal helical fibers contract and drops to 30% if only the transverse fibers shorten. This occurs when the left ventricle dilates in cardiac remodeling and the fibers lose their oblique orientation to become horizontal losing muscular and mechanical efficiency. In addition to the change in fiber orientation, there is also a decrease in shortening which contributes to reduce their power of action.

Thus, it should be understood that from the superficial to the deep fibers, a gradual change is generated in the orientation constituting the different segments of myocardial continuity. As one progresses from the base to the ventricular apex, the number of horizontal fibers decreases in relation to the oblique ones, showing that the heart is organized as a continuous helical muscle (Figure 12). The ventricular-mechanical activity is heterogeneous during diastole with subendocardial-subepicardial relaxation gradients. In systole, the muscle layers of the continuous myocardium evidence a pronounced and opposite direction of torsion in the subendocardium, in relation to the subepicardium, whereas in the apex the subepicardial fiber rotation acquires more relevance.

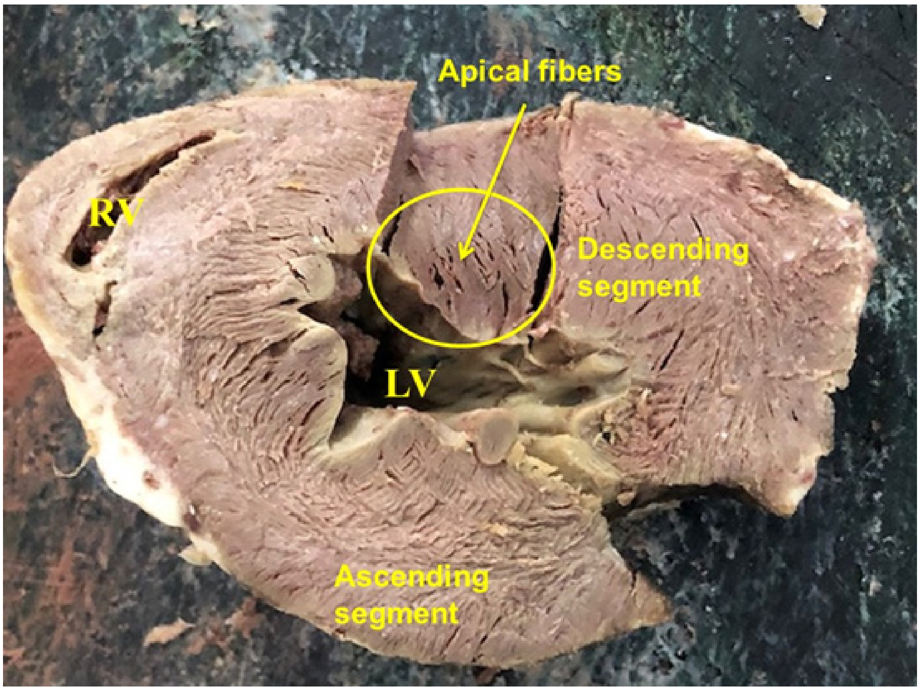

Figure 12. Spiraling fibers. The ascending and descending segments are seen in a transverse section of the heart, near the apex. It can be seen how the fibers take a spiraling shape. The subendocardial fibers (descending) have a right-hand helical direction. The subepicardial fibers (ascending), in an opposite 60º angle, represent a left-hand helical direction (bovine heart). RV: right ventricle; LV: left ventricle.

Beyond this anisotropic complexity in the continuous myocardium, the concept of linear and laminar trajectories must be established. The syncytium corresponds exclusively to the set of myocardial cells forming a bundle and not to their assembly. There is a functional integration in the myocardial structure involving from the cells, the intercellular connective tissue and the muscle fibers to the macroscopic aspects, where the sense of movement depends on their properties at a certain moment of the cardiac cycle. Myocardial muscle bundles and bands, derived from phylogenetic development, essentially shape a helical master axis of strict dynamic need.

The spatial muscular structure adopted by the helical myocardium has a dual function: a) to delimit the ventricular cavities; b) to perform the suction, reservoir, and impulse functions in its capacity as a cardiac pump. Its helical spatial morphology, which provides the turns in the continuous myocardium, enables the heart to perform its high-power muscular functions.

The boundary between the two loops, basal and apical, in the continuous myocardium is referenced by the posterior papillary muscle, which constitutes a specific anatomical fact: the second turn constituted by the sum of the 180° torque and the 90°

longitudinal torsion located between the left segment and the descending segment. It is worth noting that the left segment borders the left atrioventricular orifice. As a result, this change in direction of the myocardium, from longitudinal to having a twist at an abrupt angle of 90° with a downward orientation toward the apex, is essential for aligning the ventricles with an interdependent septum, since when the third turn occurs at the apex, the myocardium reverses its direction, fulfilling these purposes. This turn allows the direction of the fibers of the descending segment to be oriented toward the base, taking the name of ascending segment, consequently being its direction apex-base. These changes produced by myocardial twists are what allow the ventricles to align, giving the myocardium its helical arrangement in continuity with the systemic and pulmonary circulations.

In the 180° torque that occurs in the myocardium between the left segment and the descending segment, the fibers of the muscular continuity of the myocardium diverge their orientations when they intertwine due to the change in direction. This torque, together with the 90° torsion that the continuous myocardium undergoes in the second turn, allows the descending segment (continuity of the left segment) to align in a parallel and contiguous manner with the ascending segment, which arises from the continuity of the descending segment when it changes direction at the apex. At this point of proximity between the descending and ascending segments, the stimulation as it passes from the descending to the ascending segment, since its fibers have anisotropic orientations, produces a helical movement with opposing forces, which leads to myocardial torsion.(30)

In the continuous unfolding of the myocardium, the linear sequence that occurs is right segment (right ventricle) - left segment (edge of the mitral annulus and posterior wall of the left ventricle). Both segments, separated by the posterior interventricular groove, constitute the basal loop, which allows the narrowing and widening movements. In this way, the basal loop telescoping over the apical loop (descending and ascending segments) occurs like a piston, which acts as a downward plunger in a spiral rotation. The basal loop forms a rigid external cover within which the subsequent contraction of the apical loop occurs.

Following the right and left segments are the descending and ascending segments, which constitute the septum and the left ventricle. This description corresponds to an unfolded adult myocardium, which, when folded, forms a helical spatial structure. For this final morphological situation to occur, there is an embryological stage that allows for this alignment of the segments that constitute the myocardium. Thus, on day 26 of human gestation, the cardiac bulbus is aligned so that the right ventricle (bulbus) is located next to the left ventricle, which in its proximal part, bordering the left ventricle, contains the left segment. After the rotation has occurred, the right ventricle is positioned anteriorly superiorly in relation to the left ventricle, with the pulmonary artery to the left of the aorta (**Figure 13**).

At the site where the left segment takes a torque of 180° added to a torsion of 90°, continuing as a descending segment, as it remains contiguous with the ascending segment, after the third turn (apical) has occurred, an anisotropic anatomical situation is established in the fibers of both segments, which allows ventricular torsion (figure 13). As an anatomical reference, this third turn occurs at the level of the anterior papillary muscle and is the cause of the ventricles being directed, allowing the myocardial helix to form.

47. If we go back to the primary stage in the evolution of the circulatory system, the phylogenetic landmarks of the different species can be seen. The atria belong to the venous segment, and the ventricles to the arterial segment. A subsequent, more pronounced curvature of the arterial segment brings the atria into contact with their respective ventricles. In this way, the horizontal arrangement of both atria (chambers originating in the venous semicircle) is attached to the plane of the ventricular component (arterial semicircle).

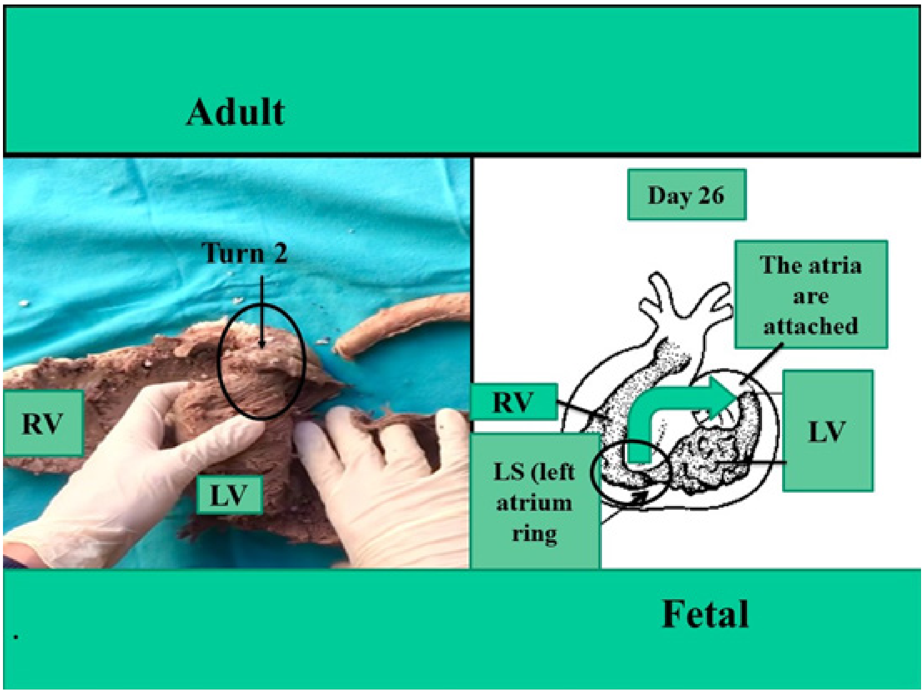

Figure 13. In the adult myocardium, torsion (black circle) is observed to form the helix and achieve the alignment of both ventricles. The green arrow in the fetal heart shows the translation of the RS (RV) and LS (black circle) to achieve this forced rotation that determines the spatial situation of the ventricular chambers. Ref. RS: right segment; RV: right ventricle; LV: left ventricle; LS: left segment.

It is also clear that when observing the heart in its natural position in the mediastinum, we easily see that the right atrium corresponds to this spatial topographical situation. The rest of the chambers are named erroneously in relation to the three-dimensional arrangement they have. The right ventricle is antero-right, practically leaving no space in this location to the ventricle, termed left ventricle, which by being displaced by the antero-right-ventricle in its counterclockwise rotation is shifted to a slightly left location, but is essentially posterior in almost all its volume, and consequently should be called posterior-left-ventricle. In turn, the left atrium is even more rotated posteriorly, to a point located behind the ascending aorta, separated from it by Theile's transverse sinus, and the tip of its appendage emerges slightly in a left position. Therefore, it should be called posterior atrium. This situation clearly explains the counterclockwise rotation of the heart in its helical conformation (**Figura 14**), determining the dynamics of both ventricles and the distribution of the energy wave in the septum (**Figures 15 and 16**) in order to cause ventricular torsion.(30)

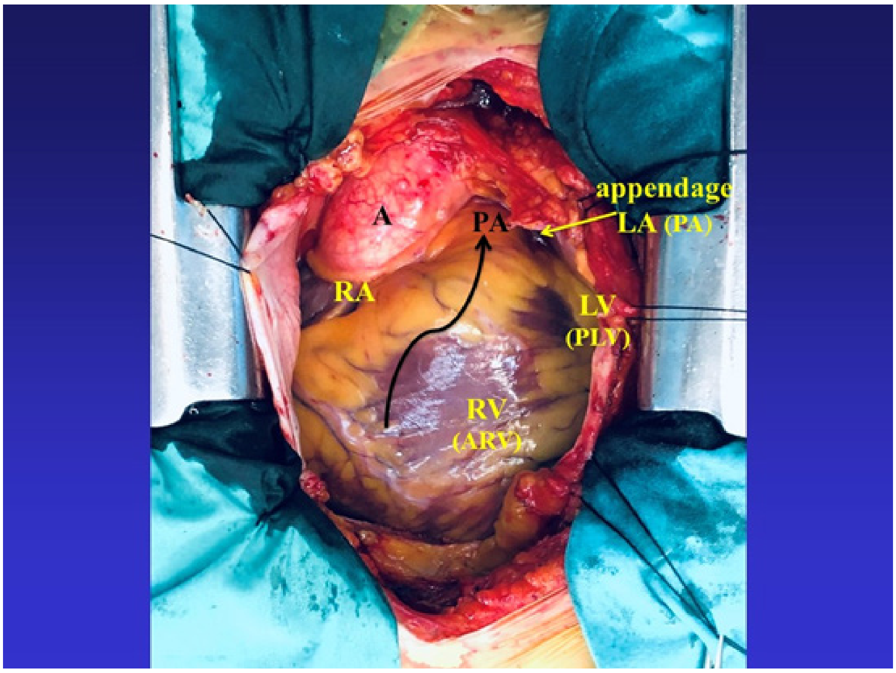

Figure 14. Photograph of an "in situ" human heart in a patient prior to heart surgery. The proposed nomenclature is shown between brackets). References. A: aorta; PA: pulmonary artery; RA: right atrium; LA (PA): left atrium (posterior atrium); LV (PLV):

left ventricle (posterior-left ventricle); RV (ARV): right ventricle (antero-right ventricle). The black arrow indicates the sense of the counterclockwise helical torsion of the venous circuit around the aorta.

With its helical configuration, but without the fulcrum, the myocardium would be a continuity without beginning or end. The fulcrum implies a necessary interruption for the support that every muscle must have. The closed fibers would determine that their stresses would be established as in a rubber band, but without an anchor point or support. The absence of the anchor point would not allow the fibers to slide properly relative to each other, losing the correct sequence of their stresses. Physically, we would speak of free and unfixed vectors, losing the correct sequence of their stresses, and the myocardium itself would not have the desired displacements but rather asynchronous vibratory movements due to muscle excitations.

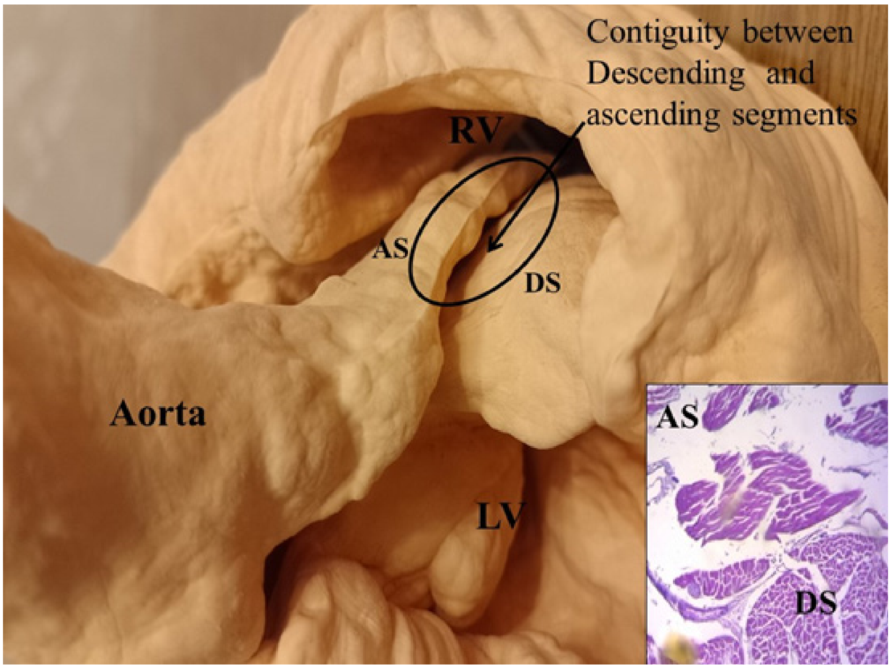

Figure 15. The model shows the contiguity between the descending and ascending segments in the folded heart (black circle) in the septum. The box shows the different anisotropic orientation of the fibers of the descending segment (DS) in relation to the ascending segment (AS). Ref. AS: ascending segment; DS: descending segment; RV: right ventricle; LV: left ventricle.

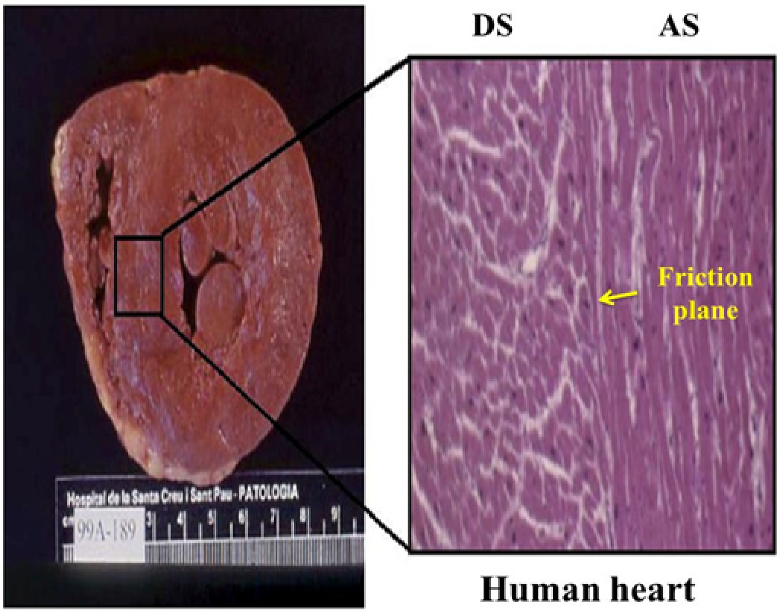

Figure 16. Microscopic view (right) of the interventricular septum medial segment in the human heart, clearly showing absence of transition circumferential fibers between the descending (right) and ascending (left) segments of the continuous myocardium. Also note that there is no fascia or anatomical structure located between the two fiber bundles. Moreover, in the macroscopic section (left), it can be seen how the sudden transition of the fiber angle change draws a line that can be perceived with the naked eye and that, in echocardiographic images, gives rise to the known medioseptal linear image generated by the acoustic interphase originating

from by the abrupt change in angulation in this region of the septum. References: DS: descending segment; AS: ascending segment.

Therefore, the existence of the fulcrum is inevitable. Furthermore, it has been proven in research published in due time that the fibers are lubricated with hyaluronic acid in order to reduce friction between them and the loss of energy, so that most of this is transformed into movement (**Figure 17**). (31)

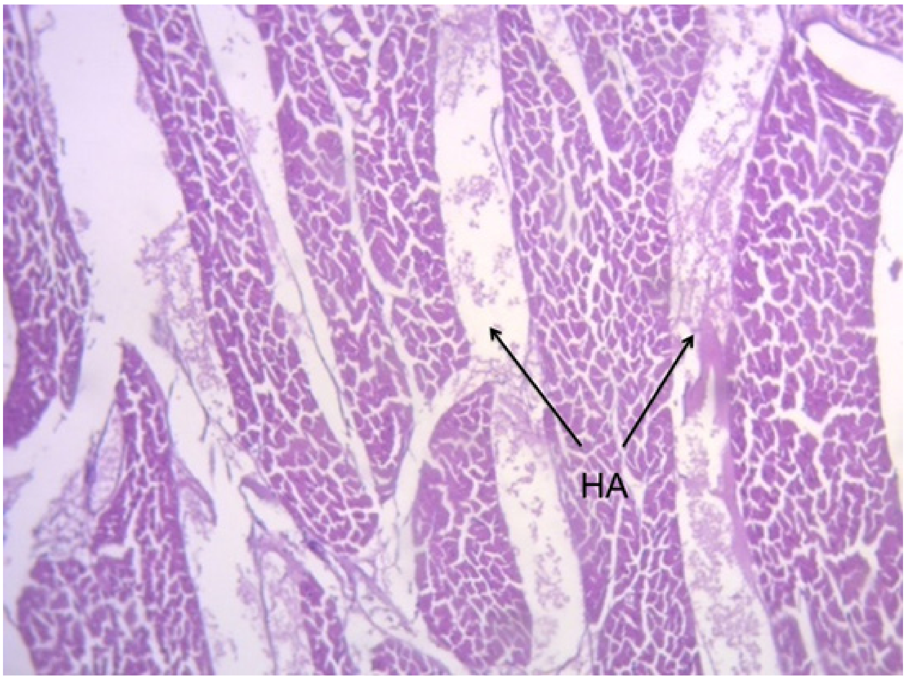

Figure 17. Interstitial space between cardiomyocytes showing hyaluronic acid (HA) stained with Alcian blue technique (15x) (adult human heart).

CONCLUSIONS

The three turns that occur in the continuous myocardium constitute a hallmark of the helical heart, since in the classic quasi-spherical system of a cavity surrounded by homogeneous muscle, the same would be meaningless to fulfill the torsion/detorsion function that the heart has. This arrangement allows the ventricles to be aligned in a contiguous manner by constituting the septum by means of directing the descending segment (continuity of the left segment) in a parallel and contiguous manner with the ascending segment, which comes from the continuity of the descending segment when it changes direction at the level of the apex, oriented towards the cardiac base. In this way, the myocardium, by achieving the proximity between the descending and ascending segments, determines with the anisotropic properties of its fibers, that the stimulation, when passing between these segments (30), can produce a helical movement with opposing forces, which leads to myocardial torsion-detorsion.

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