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ORIGINAL RESEARCH ARTICLE

Myocardial support

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ABSTRACT

Objective: The cardiac muscle cannot be anatomically free in the thorax and without a support to fulfill its hemodynamic function. Therefore, the possibility of the existence of a support point acting as a lever was analyzed. **Material and methods:** We used: 1) cardiac dissection in ten young bovine hearts [800–1000 g]; 2) cardiac dissection in eight human hearts: one embryo of 23 weeks gestation; one 10 year old, 250 g; and six adults, mean weight 300 g. The myocardial band was unwound completely. The myocardial band was uncoiled in its entirety. The extracted pieces were analyzed for anatomy and histology. The investigation was completed with simple radiographic imaging studies, magnetic resonance imaging and computed tomography. **Results:** In anatomical investigations we have found in all human and bovine hearts studied a nucleus underlying the right trigone of bone-chondroid-tendinous histological structure. Microscopic analysis revealed in bovine hearts a trabecular osteochondral matrix [fulcrum]. In all human hearts the fulcrum was found to be formed by chondroid tissue. In this structure, not described by other authors, the origin and end of the myocardial fibers have muscular insertion. Imaging techniques confirmed its existence. **Conclusions:** The cardiac fulcrum found in the anatomical investigation of human and bovine hearts would clarify about the necessary fulcrum of the myocardial muscle to complete its twisting movements.

Keywords: heart; cardiac anatomy; myocardium; myocardial support

1. Introduction

The anatomy of the myocardium was traditionally considered to be made up of spiral muscle bundles, but these were never described in consideration of their physiology. Richard Lower in 1669 considered that the myocardium produced a twisting motion related to the helical fibers that composed its fibers. He expressed that the heart exerted a movement similar to "wringing a towel" and not as Harvey considered, which was due to the ventricular radial expression with the simile of "clenching a fist"[1].

Andrés Vesalius, in his work "De Humanis Corporis Fabrica" [1543], referred to the difficulty in

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discerning the layers that make up the myocardium. He stated: “In whatever way you dissect the flesh of the heart, whether it is raw or cooked..., you can hardly pull out a portion of a single type of fiber, because they have multiple and distinct directions, especially transverse ones”[2].

More than three centuries later, Pettigrew also pointed out this situation: “Of the complexity of the disposition I need speak no more than Vesalius, Haller and De Blainville; all confessed their inability to decipher it”[3]. Shaner in 1923 reported that “the myocardium is made up of two flattened muscles in the shape of an 8. These muscles coil in the opposite direction in systole, emptying their contents”[4].

We conclude that the lack of an adequate anatomical dissection and histological analysis of the myocardium has prevented us from seeing its real structure-function. Recent interpretations hold controversial opinions, fundamentally between the developed band and mesh models. Torrent-Guasp[5,6] from 1973 onwards considered the myocardium as a cardiac muscular band, demonstrating in multiple dissections that it is constituted by a set of muscular fibers twisted on themselves that resemble a cord, flattened laterally, which when turning twice in a spiral defines a helicoid that delimits the two ventricles. Maclver[7,8] interprets that the ventricular walls are constituted by an intricate three-dimensional network of cardiomyocytes. This mesh model implies that the cardiomyocytes are arranged with radial and longitudinal angulations.

The inevitable reflection that arises is that, in order to perform torsion, the myocardium should perform it on a point of support in the same way that a skeletal muscle does on a firm insertion. If this support is real, how are the fibers of the cardiac muscle inserted in this structure? Can it be differentiated from trigones?

This study situation correlates with a cardiac structure that presents notable characteristics: that of being a suction-impeller pump of a size equivalent to a human fist and an average weight of 270 grams, which propels 4 to 6 liters/minute at a velocity of 300 cm/s. Its efficiency allows 70% of the left ventricular content to be expelled with only 12% shortening of its contractile unit, the sarcomere.

The aim of this work is to demonstrate by means of macroscopic dissections and microscopic studies that the myocardium is a continuous, single, helically arranged muscle that needs a fulcrum as a lever. All these investigated anatomical-functional considerations can help both in the process of quantifying the severity of morbid processes and in therapeutic strategies[9].

2. Material and methods

2.1. Myocardial dissection in eighteen hearts

a) ten two-year-old bovine hearts weighing 800-1000 g; b) eight human hearts: One 23-week gestation embryo, one from a 10-year-old person weighing 250 g, and six in adults weighing an average of 300 g.

2.2. Histological and histochemical analysis of anatomical samples

Histology was performed with hematoxylin-eosin, Masson’s trichrome staining technique and four-micron sections. Formalin 10% was used as buffer. All samples were subjected to histological and histochemical analysis with alien blue staining, a reliable marker to identify the presence of hyaluronic acid, as an antifriction mechanism, and even to provide a semiquantitative assessment.

2.3. Imaging studies

Bovine hearts were analyzed with computed tomography, magnetic resonance imaging and plain radiology. One patient could be studied with tomography.

The hearts examined were provided by the morgue and by slaughterers. The heart to be dissected should be boiled in water for two hours to which it is convenient to add acetic acid [15 cc per liter]. This step allows the myocardium to be free of fatty appositions, making dissection easier and neater. Then the aorta and the pulmonary artery are sectioned about three centimeters from their origin and separated from the attachment that these vessels have between them, and then longitudinally incised at the level of the interventricular groove, the superficial fibers that extend transversely along the anterior face of the ventricles. Between the atria and the ventricles there is simply conjunctive tissue, which allows the separation of these chambers with simplicity, given the denaturation established by heat[10].

The key maneuver to achieve myocardial uncoiling consists of bluntly entering the anterior interventricular groove, which allows the end of the myocardium corresponding to the pulmonary artery and its contiguity with the free wall of the right ventricle [right segment] to remain on the operator's left side. Traction is then exerted towards the same left side, a maneuver that leaves the pulmonary artery completely free from the rest of the myocardium. This dissection of the myocardium reveals the fulcrum below and in front of the aorta in a plane inferior to the right trigone and the origin of the right coronary artery, without continuity with the aortic valve and inserted as a complementary element between the aorta and myocardium. This structure, which supports the initial and end of the cardiac muscle, is more rigid in consistency than the trajectory between the trigones.

When the myocardium is unfolded, separating the pulmonary artery and the pulmotricuspid cord [anterior] from the ascending segment [posterior], the vision of its homogeneous and functional anatomical integrity is lost. This conjunction between the origin and termination of the cardiac muscle at 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 located at the same point, the origin of the myocardial fibers being in an anterior plane to those of its termination.

The continuation of myocardial dissection involves encountering the entire extension of the right segment, the beginning of the left segment, and at the posterior limit of the right ventricular cavity, the dihedral angle formed by the interventricular septum and the free wall of the right ventricle [right segment]. The next step [the most delicate] consists of positioning in the dihedral angle mentioned above, between the fibers of the right ventricle and the intraseptal fibers. This separation of the right ventricle allows entering the ventral part of the septum. The dorsal part of the septum is then dissected to disassemble and separate the aorta.

Finally, the muscular plane of the descending segment is bluntly separated from that corresponding to the ascending segment that leads to the cardiac fulcrum in contiguity with the aorta, to the right of the operator, allowing it to be extended along its entire length. By being able to unroll the myocardium in a similar thickness along its entire length, it is evident that it is unique and continuous, and not a heuristic construction.

3. Results

In all the human and bovine hearts studied, we found a nucleus underlying the right trigone, whose histological bone, chondroid or tendon structure depends on the specimen analyzed (**Figures 1–3**). Microscopic analysis revealed in the hearts a trabecular osteochondral matrix [fulcrum] with segmental lines in bovines (**Figures 1** and **2**). In the 10-year-old human heart, a central area in the fulcrum formed by chondroid tissue was found (**Figure 4A**). In the fetus, prechondroid areas were found in a myxoid stroma (**Figures 4B**). In adult human hearts, histological analysis revealed a tendon-like matrix. All hearts studied had myocardial insertion into the rigid fulcrum structure (**Figures 2** and **5**). No myocardiocytes were found in either the left or right trigone or at the base of the valves.

This attachment point implies, as in any skeletal muscle, its capacity to achieve the necessary support and also to act as a bearing or cushion, preventing the force of ventricular rotation, whether by torque or torsional stress, from being transferred to the aorta, thus dissipating the energy produced by the movement of the helical muscle and avoiding aortic constriction or flexion during systolic ejection.

The radiological images evidenced the osteochondroid nucleus found in the dissection, observing the same morphology and analogous size (**Figure 1**). In the tomography of a patient studied we found that the analysis of the region described as cardiac fulcrum in the dissections performed, has an intensity in Hounsfield units above 110 HU, while the adjacent muscle has units below 80 HU. In this patient, in the area described as fulcrum, an average of 132 ± 4.5 HU was found and in the areas adjacent to the myocardial muscle between 47.96 ± 12.5 and 77.59 ± 21.64 HU.

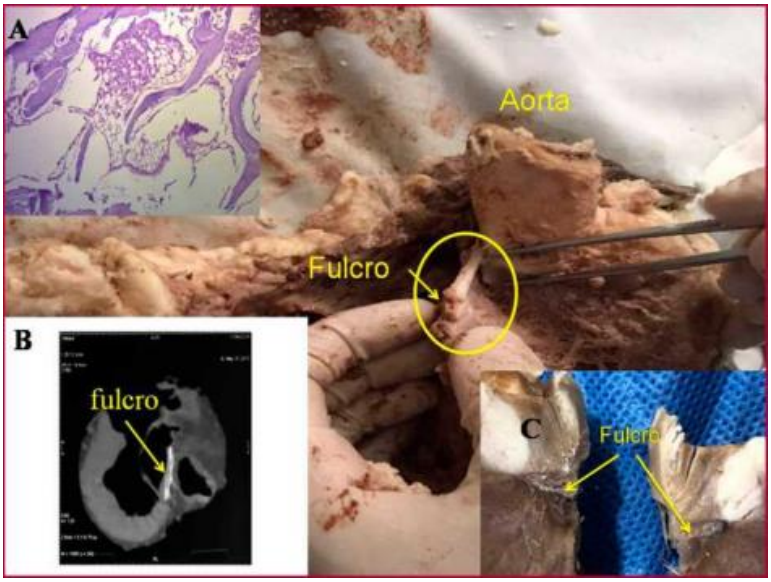

Figure 1. Cardiac fulcrum [bovine heart]. **(A)** Mature bone trabeculae configuring the cardiac fulcrum tissue. Hematoxylin-eosin technique [10×]; **(B)** the area marked with the arrow shows an image adjacent to the aortic root over the interventricular septum [computed tomography]; **(C)** another view of the fulcrum.

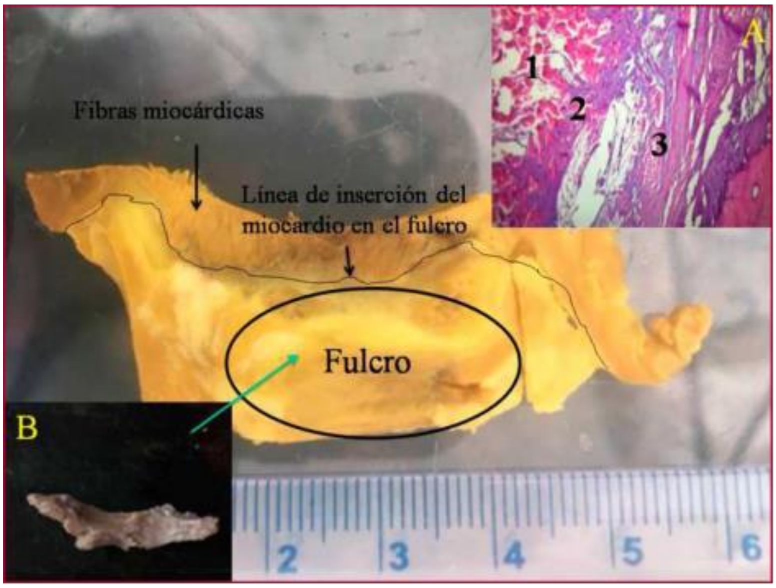

Figure 2. Note the line of insertion of myocardial fibers in the fulcrum of a bovine heart. Histology of the insertion **(A)** Myocardial fibers and myxoid stroma. Myocardial ribbons in a chondroid stroma [insertion]. Bone cortical tissue of the fulcrum. Hematoxylin-eosin technique [15×]; **(B)** Resected piece.

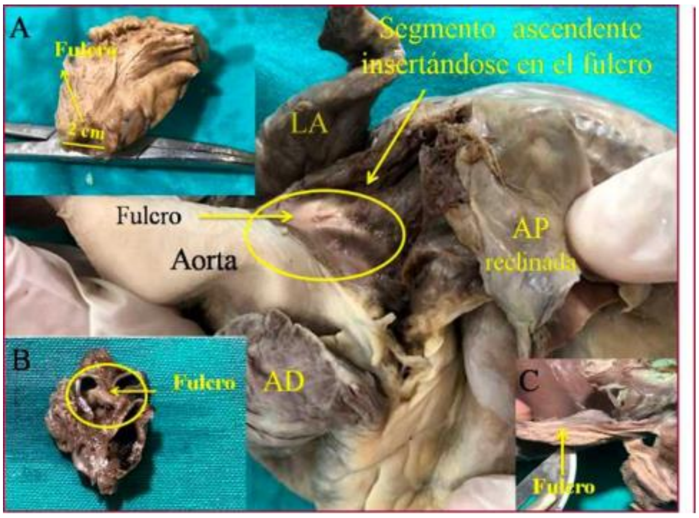

Figure 3. Cardiac fulcrum [human heart]. **(A)** 10 years of age; **(B)** Human embryo of 23 weeks gestation; **(C)** Resected fulcrum belonging to an adult human heart.

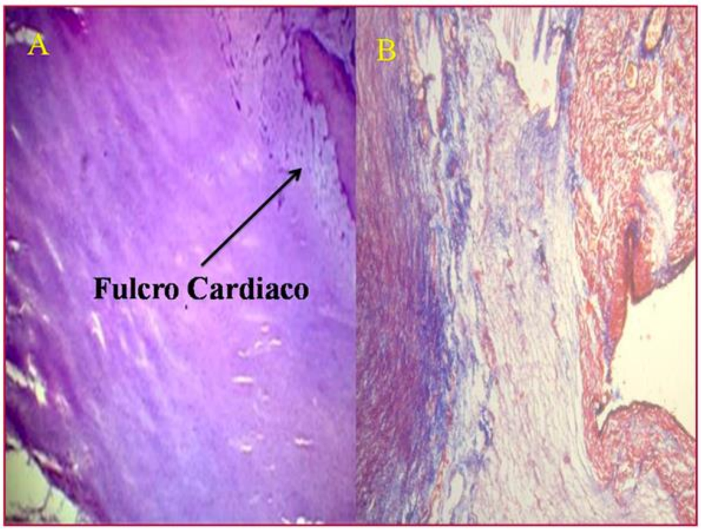

Figure 4. (A) 10-year-old human heart. Central zone: area of the fulcrum formed by chondroid tissue. Hematoxylin-eosin technique [15×]; **(B)** Prechondroid bluish areas in a myxoid stroma in a 23-week gestation fetus. Masson's trichrome technique [15×].

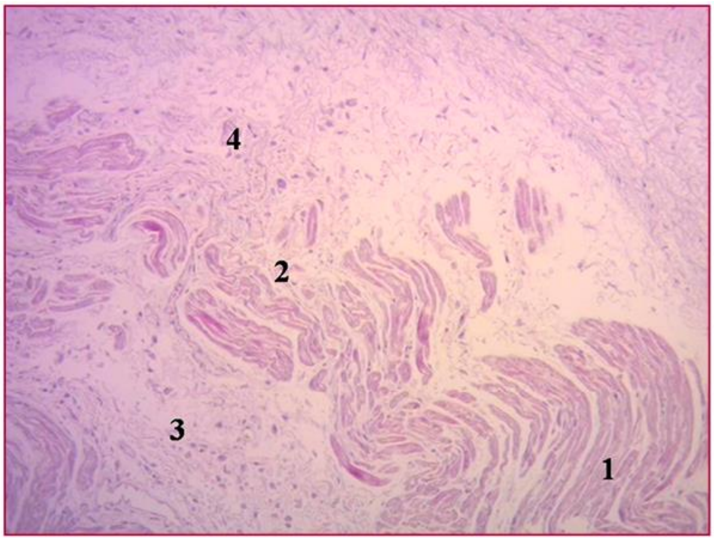

Figure 5. Fetal myocardiocytes penetrating a fibrocollagenous matrix [adult human heart]. Myocardiocytes, Myocardiocyte dehylation; Atrophic myocardiocytes, Fibrocollagenous matrix. Hematoxylin-eosin technique [15×].

4. Discussion

In the investigation carried out, a nucleus of a bony, chondroid or tendinous nature was found in all bovine and human hearts, which we have called the cardiac fulcrum. The fibers of the right segment and of the ascending segment, origin and end of the cardiac muscle, are oriented towards this nucleus and are inserted into it.

The existence of this formation, called cordis, in bovids, sheep and chimpanzees is a fact mentioned in veterinary literature, without any physiological connotation. It is located in the same place where we have found and investigated this structure in both bovids and humans. Beyond its mere allusion in bovids, no function or significance of its presence has ever been assigned to it, and likewise it lacks description in humans.

In the human hearts analyzed, the findings are surprising from the point of view of interpretation, on the basis that it is logical to consider its presence throughout the evolutionary chain of mammals. It should be considered that this structure, when analyzed in the different specimens, has in common its function of supporting the myocardium in order to generate the power needed by any muscle, which is different in different mammals. Therefore, its presence is constant in all the analyzed hearts of both bovids and humans, but its structural characteristic is different. And this difference in the intimate analysis of the cardiac fulcrum is undoubtedly related to the resistance that it must oppose to the action of the cardiac muscle in hearts of different sizes.

A fact that satisfies the logic of myocardial structure and mechanics is to have found in the human heart, with the same location and similar triangular morphology mentioned in different species, this tethering of myocardial fibers of unequivocal characteristic to simple observation and palpation. However, histological analysis in the adult human heart revealed a tendon-like matrix. At this point, fundamental questions arise: Why does the human fulcrum have tendon-like characteristics, even though it fulfills the same function of tethering the myocardium to a support that other species have? Why does it not have the same structure as the fetal or infant human heart?

The interpretation we have is that perhaps the bone characteristic fulcrum in bovine, chimpanzee, sheep and human embryo, is a vestigial organ characteristic of the evolution of mammals. A vestigial structure should be understood as the retention during the process of evolution of genetically determined attributes that have lost part or all of their ancestral function in a given species. Due to this fact we find it in the initial process of the human gestation, but then its bony character disappears, being referred to a tendinous matrix sufficient to achieve the insertion of the myocardium to comply with a muscular power inferior to other larger mammals. Let us remember that in bovines the fulcrum found in this research is of a bony nature.

The myocardium is a continuous and helical muscle, which is the result of its dissection. Cardiac function cannot be explained by a mesh conformation. In this regard, Maclver's work[7] states: "None of the histological studies of the myocardium of which we are aware, on the contrary, have provided any evidence of an origin and insertion as described for the supposed single myocardial band" and "None of these investigations have provided any evidence of an alignment of cardiomyocytes that follows the course of the single myocardial band". First, the cardiac fulcrum that we have investigated in human and animal hearts describes the cardiac support that would give rise to the single, continuous, helical muscular arrangement that the myocardium exhibits.

With respect to the second conclusion of the aforementioned author, the sequence of histological analysis of the unfolded myocardium demonstrates the longitudinal orientation, according to the continuity of the segments that has its spatial conformation, both on the internal and external face of each segment. These orientations are parallel on both surfaces [internal and external] in each of them. No segment of the sequential histology in the longitudinal continuity of the myocardium presents a mesh arrangement. In the external face of the distal part of the descending segment, when turning at the level of the apex and becoming ascending, the myocardiocytes generate in the planimetric sections an architecture dissimilar to the internal face in its orientation, the only site where this situation occurs. In the rest, the orientation is always parallel. At the apex, the spiral trajectory of the myocardial fibers that move from the periphery towards the center determines a torsion in which the subepicardial fibers become subendocardial, superimposed like the tiles on a roof, which is what is evident in the commented image. This resembles a Moebius strip given the progressive change in angulation of the fibers transforming from epicardial to endocardial.

It can be observed that the myocardium is not structured as a mesh but as a continuous muscle[11,12]. The concept of mesh was elaborated through the folding of the myocardial helix by superimposing its segments.

Histological analysis of the trigones has also been performed to find cardiomyocytes in them, as a possibility of myocardial insertion in these structures. In our investigation, only collagen tissue without cardiomyocytes was observed in the trigones, confirming that the fulcrum is the support of the cardiac muscle, both at its beginning and at its termination.

The myocardium cannot be anatomically suspended and free in the thoracic cavity because it would be impossible for it to eject the blood from the heart at a speed of 300 cm/s. There had to be an anchorage site which, once found, we call the cardiac fulcrum. At this point of support, the muscle fibers are inevitably obliged to intertwine with the fulcrum, which, of a connective, chondroid or bony nature, showed in our anatomical and histological investigations this insertion, holding both the beginning and the end of the cardiac muscle.

In the fulcrum the heart finds the fixed point that allows the mechanics of muscular torsion. The opposite rotation of the left ventricle from the base and apex[13,14] allows the development of high pressures that reduce tension, exactly like "wringing out a towel". This mechanics, found in mice and humans[15–18], facilitates the expulsion of the hematic content with the necessary force in a limited time to sufficiently irrigate the whole organism.

5. Limitations

The human specimens studied were scarce because it is difficult to obtain intact and well-preserved hearts for meticulous dissection. We believe that the work should be expanded with a larger number of human hearts, adults and especially children. Our investigation was limited to eighteen hearts, eight human and ten bovine.

6. Conclusions

The cardiac fulcrum found in this anatomical investigation would clarify the fulcrum of the myocardial band to complete its torsional function. Without its presence, the heart would not be able to achieve its hemodynamic efficiency of ejecting blood at a velocity of 300 cm/s.

Author contributions

Conceptualization, JT; methodology, JL; software, DCM, MEB; validation, JT, JL and MB; formal analysis, DHL; investigation, MB, JT, MW; resources, AT; data curation, DHL; writing—original draft preparation, JT, MEB; writing—review and editing, JT, JL, MB; visualization, DCM, AT; supervision, JT, MW, JL; project administration, MEB, DHL. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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