ORIGINAL ARTICLE

The Myocardial Support

El soporte del miocardio

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ABSTRACT

Background: The cardiac muscle cannot be anatomically free in the thorax and without a support to fulfill its hemodynamic function. Therefore, we analyzed the possibility of a supporting point, acting as a lever.
Material and Methods: Cardiac dissection was performed in ten young (two-year-old) bovine hearts (800-1000 g); and in eight human hearts: one belonging to a 23-week gestation fetus, one to a 10-year-old child, weighing 250 g, and six to adult patients, with mean weight of 300 g. The myocardial band was totally unfolded. The different pieces were anatomically and histologically analyzed and the study was completed using magnetic resonance imaging, computed tomography and simple radiology.
Results: In the anatomical investigation of all the human and bovine hearts studied we found a nucleus underlying the right trigone, of osseous, chondroid or tendinous histological structure. The microscopic analysis revealed in bovine hearts a trabecular osteochondral matrix (fulcrum) and in human hearts the fulcrum was formed by chondroid tissue. The origin and end of the myocardial fibers were inserted into this structure, not previously described by other authors. Imaging studies confirmed the existence of the cardiac fulcrum.
Conclusions. The cardiac fulcrum found in the anatomical investigation of bovine and human hearts would clarify the supporting point of the myocardial muscle to complete its torsion motion.

Key words: Heart – Cardiac anatomy – Myocardium- Cardiac support

RESUMEN

Objetivo: El músculo cardíaco no puede estar anatómicamente libre en el tórax y sin un soporte para cumplir con su función hemodinámica. Por tanto, se analizó la posibilidad de la existencia de un punto de apoyo que actuara a modo de palanca.
Material y métodos: Se utilizaron: 1) disección cardíaca en diez corazones bovinos jóvenes (dos años) (800-1000 g); 2) disección cardíaca en ocho corazones humanos: un embrión de 23 semanas de gestación; uno de 10 años, 250 g; y seis adultos, peso medio 300 g. La banda miocárdica se desenrolló en su totalidad. Las piezas extraídas fueron analizadas por anatomía e histología. Se completó la investigación con estudios de imágenes radiográficas simples, resonancia nuclear magnética y tomografia computada.
Resultados: En investigaciones anatómicas hemos encontrado en todos los corazones humanos y bovinos estudiados un núcleo subyacente al trígono derecho de estructura histológica ósea-condroide-tendinosa. El análisis microscópico reveló en corazones bovinos una matriz osteocondral trabecular (fulcro). En todos los corazones humanos se encontró que el fulcro se halla formado por tejido condroide. En esta estructura, no descrita por otros autores, tienen inserción muscular el origen y el final de las fibras miocárdicas. Las técnicas con imágenes confirmaron su existencia.
Conclusiones: El fulcro cardíaco encontrado en la investigación anatómica de corazones humanos y bovinos aclararía sobre el necesario punto de apoyo del músculo miocárdico para completar sus movimientos de torsión.

Palabras clave: Corazón – Anatomía cardiaca – Miocardio- Apoyo miocárdico

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INTRODUCTION

The anatomy of the heart was traditionally considered to be formed by muscles arranged in spiraling bundles, but these were never described in relation to their physiology. Richard Lower in 1669 considered that the myocardium was subjected to a torsion motion related to the helical fibers that formed it. He expressed that the heart exerted a motion similar to "wringing a towel" and not as it was considered since Harvey who claimed it was due to ventricular radial compression comparable to "closing a fist". (1)

Andreas Vesalius in his work "De Humani Corporis Fabrica" (1543) referred to the difficulty in identifying the myocardial layers. He expressed verbatim: "No matter how you perform the dissection of the meat of the heart, whether raw or cooked…, you can scarcely remove a portion of only one type of fiber, because they have multiple and different directions, especially transversal". (2)

Three centuries later, this situation was also remarked by JB Pettigrew (1864) "Of the complexity of the arrangement I don´t need to say more than Vesalius, Haller and De Blainville; they all confessed their inability to decipher it". (3) RF Shaner in 1923 states that "the myocardium is formed by two flattened muscles with the shape of an 8. These muscles twist in opposite directions in systole, emptying their content". (4)

Lack of an adequate anatomical dissection of the myocardium prevented seeing its real functional structure. Recent interpretations pose controversial opinions, mainly between band and mesh models. Torrent Guasp (5, 6) in 1973 considered the myocardium as a cardiac muscle band, showing in numerous dissections that it is formed by a set of muscle fibers coiled unto themselves similar to a rope, flattened laterally, which by giving two spiraling turns define a helix limiting the two ventricles. MacIvear (7, 8) explains that the ventricular walls are shaped by an intricate cardiomyocyte three-dimensional mesh, implying that cardiomyocytes are arranged with radial and longitudinal angulations.

The inevitable reflection that arises is that to fulfill torsion, the myocardium must perform it on a supporting point, same as the skeletal muscle does it on a firm insertion. Does that structure exist in the heart? If this supporting point is real, how are the cardiac muscle fibers inserted into this structure? Can it be differentiated from the trigones? This premise correlates with a cardiac structure presenting remarkable characteristics: that of being a suction-impelling pump, equivalent to a human fist, weighing an average of 270 grams, which ejects 4 to 5 liters/minute of blood at a speed of 300 cm/s with an efficacy that allows pumping 70% of the left ventricular volume with only 12% shortening of its contractile unit, the sarcomere.

The aim of this work was to demonstrate through macroscopic dissection and histological studies that the myocardium is a continuous, single muscle with helical arrangement. All these anatomo-functional considerations may help both to quantify the severity of morbid processes as in therapeutic strategies. (9)

METHODS

1) Myocardial dissection of 18 hearts: a) 10 two-year-old bovine hearts with an average weight of 800-1000 g; b) 8 human hearts: one from a 23-week gestation fetus; one from a 10-year-old child weighing 250 g and 6 adult hearts with an average weight of 300 gr.
2) Histological and histochemical analysis of anatomical samples. The histological study was performed using 10% formalin as buffer, 4-micron sections and hematoxylin-eosin and Masson's trichrome staining. All samples underwent histological and histochemical analysis using Alcian blue staining as a reliable marker to identify the presence of hyaluronic acid as an antifriction mechanism. and even provide a semiquantitative assessment.
3) Imaging studies. Bovine hearts were studied with computed tomography, nuclear magnetic resonance imaging and simple X-rays. One patient could be studied with a computed tomography scan.

The hearts examined were obtained from the morgue and slaughterhouse. In order to dissect it, the heart must be boiled in water during two hours with the convenient addition of acetic acid (15 ml per liter). This step removes the fat attached to the myocardium, making the dissection easier and neater. The aorta and the pulmonary artery are then cut at three centimeters from their origin, separating the attachment between them, followed by a longitudinal incision at the level of the interventricular sulcus of the superficial fibers extending transversally along the anterior wall of the ventricles. As there is only connective tissue between the atria and the ventricles, the denaturation process produced by heat allows the easy separation of these chambers.

The key maneuver to unfold the myocardium consists in entering the anterior interventricular sulcus with a blunt instrument, leaving on the left side of the operator the muscle end corresponding to the pulmonary artery and its contiguity with the right ventricular free wall (right segment). Then, traction is applied towards the same left side, a maneuver which completely releases the pulmonary artery from the rest of the myocardium. This myocardial dissection exposes 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 the myocardium. This structure, the supporting site of the origin and end of the cardiac muscle, is more rigid than the trajectory between the trigones.

It should be understood that as the myocardium is unfolded, separating the pulmonary artery and the pulmo-tricuspid cord (anterior) from the ascending segment (posterior), the vision of the homogeneous anatomical integrity is lost. This conjunction 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 progress of the myocardial muscle dissection implies finding the whole length of the right segment, the origin of the left segment and, at 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). The next step (the most delicate one) consists in approaching the dihedral angle between the right ventricular and intraseptal fibers. This separation from the right ventricle allows access to the ventral part of the septum. Then, the dorsal part of the septum is dissected to detach and separate the aorta.

Finally, to the right of the operator, the muscle plane of the descending segment is separated in blunt fashion from the one corresponding to the ascending segment leading to the cardiac fulcrum next to the aorta, allowing it to be extended in its full length. Being able to unfold the myocardium with a similar thickness in all its length shows that it is a single and continuous muscle and not a heuristic construction.

RESULTS

In all the human and bovine hearts studied we have found a nucleus underlying the right trigone, whose osseus, chondroid or tendinous histological structure depends on the specimens analyzed (Figures 1 to 3). The microscopic analysis of the hearts revealed an osterochondral trabecular matrix (fulcrum), with segmental lines in bovines (Figures 1 and 2). A central zone, formed by chondroid tissue was found in the fulcrum of the 10-year-old human heart (Figure 4A) and prechondroid areas in myxoid stroma in the fetus fulcrum (Figures 4 B), while in adult human hearts, the histological analysis revealed a matrix similar to that of a tendon. All the hearts presented myocardial insertion into the rigid structure of the fulcrum (Figures 2 and 5) No cardiomyocytes were found either in the left or right trigone or at the base of the cardiac valves.

This fixation point implies, as in any skeletal muscle, its ability to achieve the necessary support and also to act as a bearing or pad preventing the ventricular rotation force, either by torque or torsion, from spreading to the great vessels, thus dissipating the energy produced by the helical motion of the muscle and avoiding aortic constriction or flexion during systolic ejection.

Radiological images evidenced the osteochondral nucleus found in dissections, with the same morphology and analogous size (Figure 1). In computed tomography scans, we saw that the analysis of the region described as cardiac fulcrum in the dissections performed had an intensity above 110 Hounsfeld units (HU), while the adjacent muscle had values below 80 HU. In one patient, the area described as fulcrum had a mean value of 132±4.5 HU, and in the adjacent areas this value was 47.96±12.5 and 77.59±21.64 HU.

DISCUSSION

In all the bovine and human hearts used in this research, we found an osseous, chondroid or tendinous nucleus, which we have termed cardiac fulcrum. Fibers from the right segment and the ascending segment, i.e., the origin and end of the cardiac muscle, are oriented and inserted into this fulcrum.

The existence of the "os cordis", a formation found in bovine, sheep and chimpanzee hearts is a fact mentioned in veterinary medicine, without any physiological relationship. It is located in the same position in which we have investigated this structure, both in bovines and humans. Beyond its mere mention in bovines, it was never assigned any function or significance of its presence, and it also lacks description in humans.

In the human hearts analyzed, the findings are

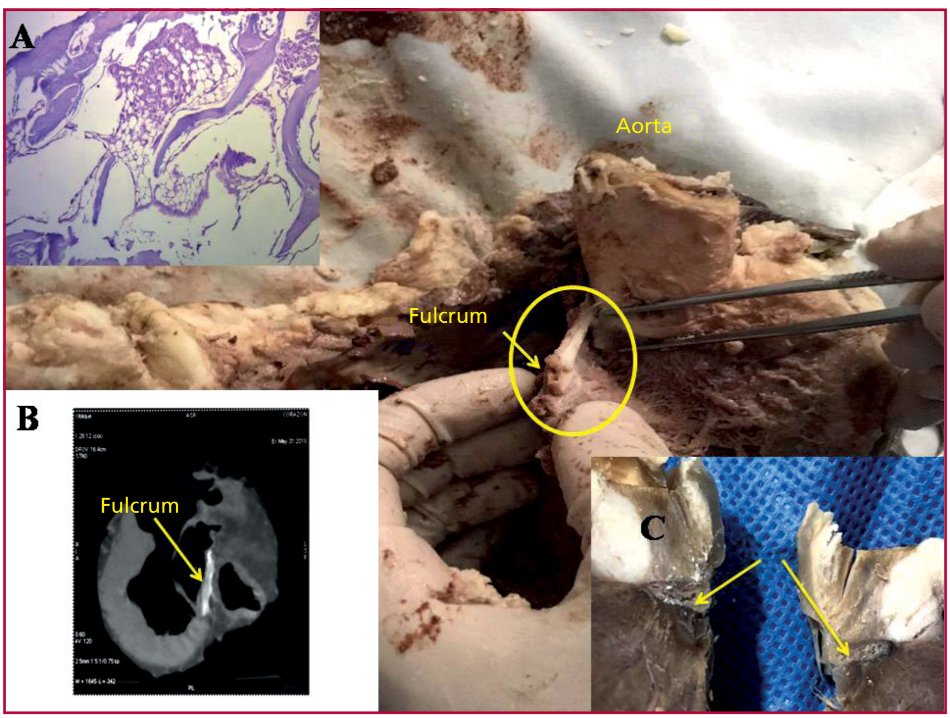

Fig. 1. Cardiac fulcrum (bovine heart). A: Mature osseous trabecula forming the cardiac fulcrum. Hematoxylin-eosin technique. (10x); **B:** In the area shown with the arrow, an image adjacent to the aortic root is observed on the interventricular septum (computed tomography); **C:** Another view of the fulcrum.

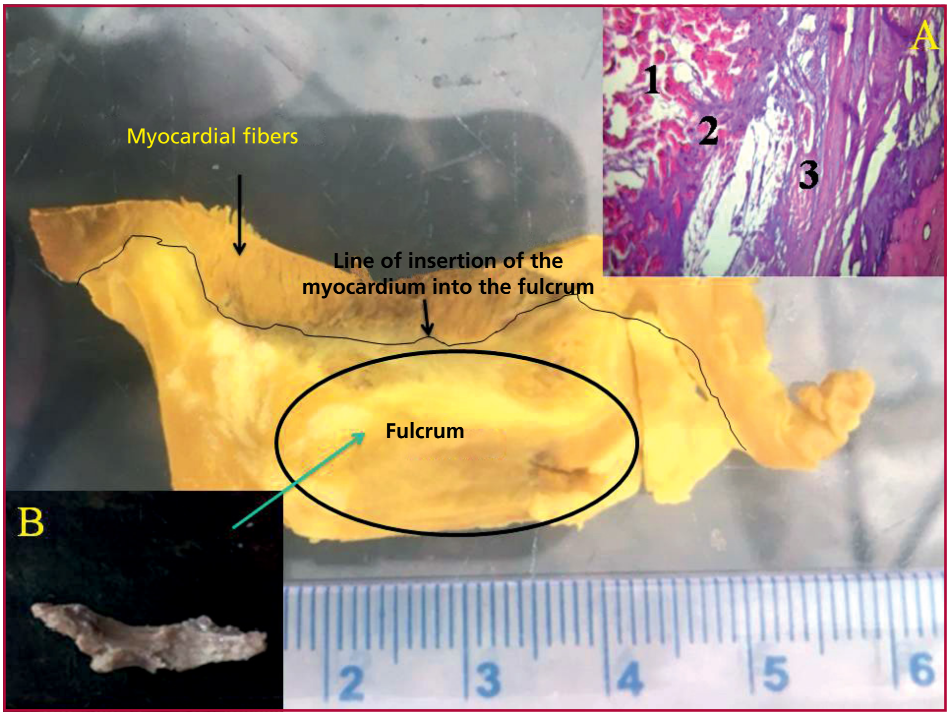

Fig. 2. Note the insertion line of the myocardial fibers in the fulcrum of a bovine heart. Histological image of the insertion. **A:** 1) Myocardial fibers and myxoid stroma. 2) Myocardial bands in a chondroid stroma (insertion). 3) Osseous cortical tissue of the fulcrum. Hematoxylin-eosin technique (15x). **B:** resected piece.

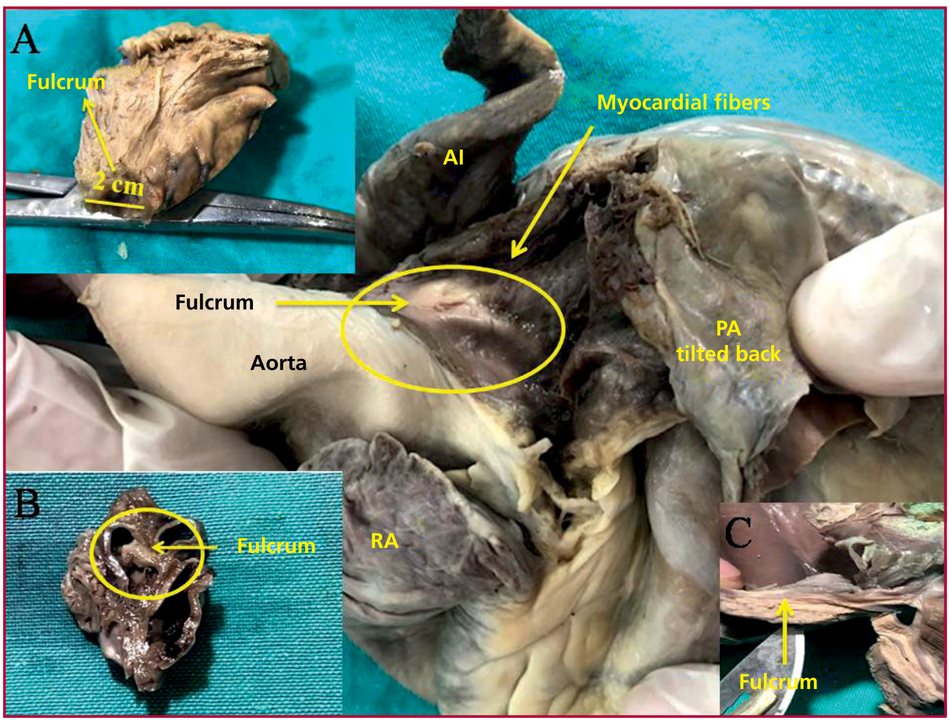

Fig. 3. Cardiac fulcrum (human heart). A: 10-year-old; **B:** 23-week gestation human fetus; **C:** Resected fulcrum belonging to a human adult heart.

remarkable from an interpretative point of view, assuming that it is logical to consider its presence in all the evolutionary history of mammals. This structure, when analyzed in the different specimens, has the common function of providing support for the myocardium to generate the strength needed by any muscle, which varies in different mammals. Therefore, its presence is constant in all the hearts analyzed, both bovine and human, but its structural characteristic is different. And this difference in the intimate analysis of the cardiac fulcrum is undoubtedly associated with the resistance it must oppose to the cardiac muscle action in hearts of different sizes.

A fact that satisfies the structural and mechanical logic of the myocardium is finding in the human heart this point of attachment of myocardial fibers of unequivocal characteristics to simple observation and palpation, in the same location and with similar

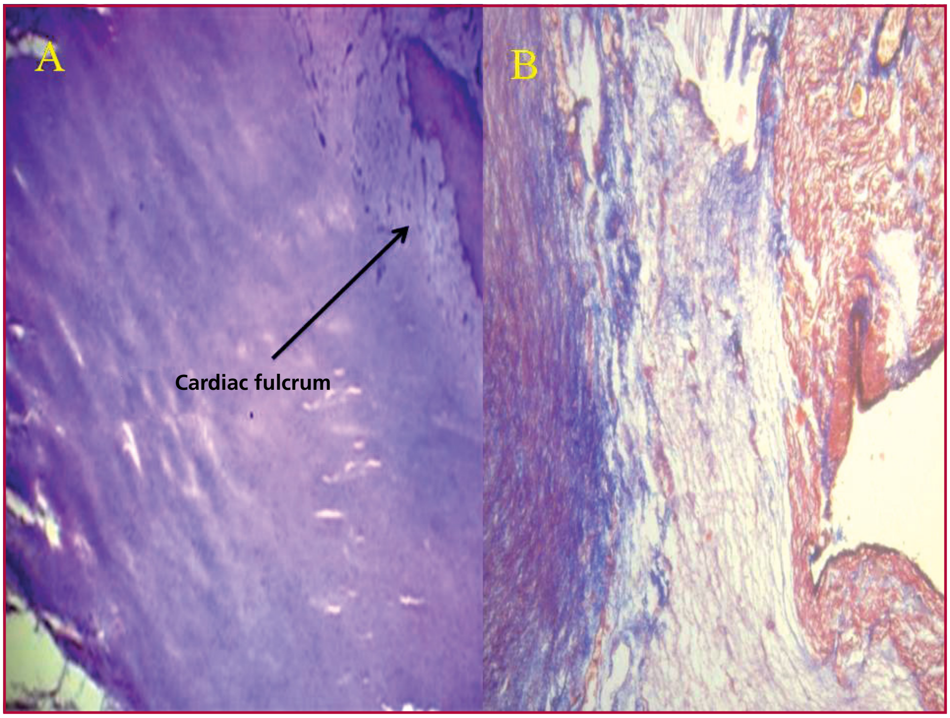

Fig. 4. A: 10-year-old human heart. Central zone of the fulcrum consisting of chondroid tissue. Hematoxylin-eosin technique (15x). **B:** Prechondrial bluish areas in a myxoid stroma in a 23-week gestation fetus. Masson's trichrome technique (15x).

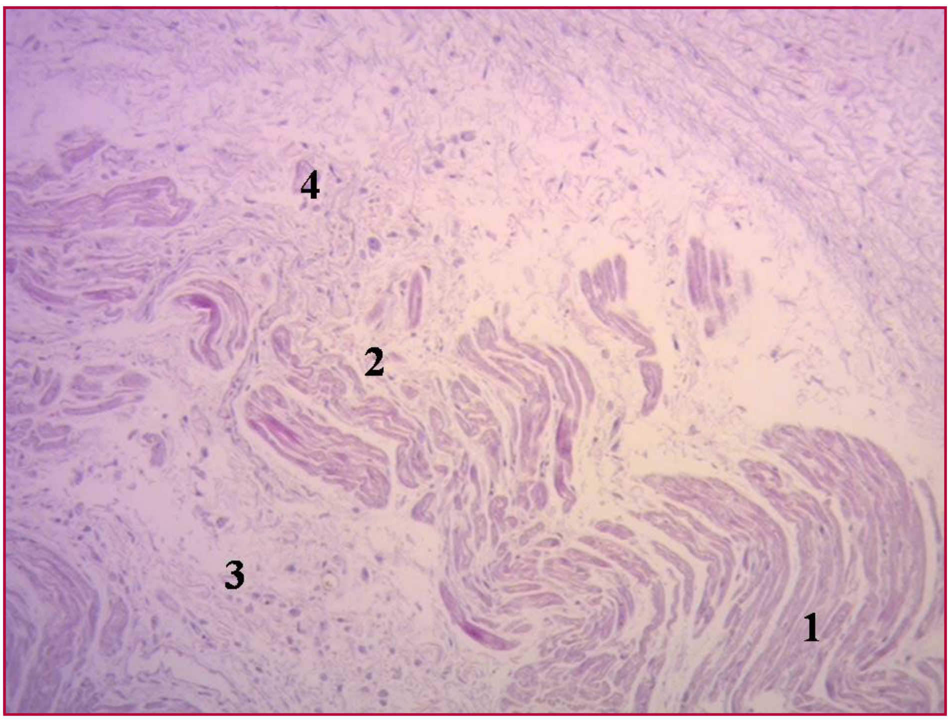

Fig. 5. Scalloped cardiomyocytes penetrating a fibrocollagenous matrix (adult human heart).
1: Cardiomyocytes 2: Cardiomyocyte fraying; 3: Atrophied cardiomyocytes, 4: Fibrocollagenous matrix. Hematoxylin-eosin technique (15x).

triangular morphology as that mentioned in different species. However, the histological analysis in the adult human heart revealed a matrix similar to that of a tendon. At this point, several questions arise: Why does the human fulcrum have characteristics similar to a tendon, despite it fulfills the same function of attaching the myocardium to a support as in other species? Why does it not have the same structure as in the human fetal or childhood heart?

The interpretation we have is that perhaps the osseus fulcrum in bovine, chimpanzee, sheep and human fetus is a vestigial organ inherent to mammalian evolution. A vestigial structure must be understood as the preservation during the evolutionary process of genetically determined traits which have partly or totally lost their ancestral function in a certain species. As a result, we find it in the initial process of human development, but then its osseous nature disappears, remaining as a tendinous structure sufficient to achieve the myocardial insertion that generates a muscle strength inferior to that of larger mammals. Let us recall that in our research the nature of the bovine fulcrum is osseous.

The results of the dissection showed that the myocardium is a continuous, helical muscle. Cardiac function cannot be explained by a mesh configuration. (25) In this regard, Maclver's work states: "None of the histological studies of the myocardium that we are aware, in contrast have provided any evidence for an origin and insertion as described for the alleged unique myocardial band" and "None of these investigations have provided any evidence of an alignment of the cardiomyocytes that follows the course of the unique myocardial band." (3) First of all, the cardiac fulcrum that we have investigated in human and animal hearts describes the cardiac support that would give rise to that single, continuous, helical muscular myocardial conformation. Regarding the second conclusion of this author, the sequential histological analysis of the unfolded myocardium shows the longitudinal orientation of fibers in agreement with the continuity of the segments resulting from its spatial arrangement, an orientation that is parallel both in the internal and external surfaces of each segment (Figure 2).

No segment of the histological sequence corresponding to the longitudinal continuity of the myocardium presents a mesh configuration. In the external surface of the distal end of the descending segment, when it turns at the apex and becomes the ascending segment, the orientation of the cardiomyocytes generates, in planimetric sections, a dissimilar architecture in their orientation to that of the internal surface, only place where this situation occurs. The rest of the orientation is always parallel. In the apex, the spiraling course of the myocardial fibers which shift from the periphery to the center determines a torsion in which the subepicardial fibers become subendocardial, overlapping like the tiles of a roof, as depicted in the aforementioned figure. This resembles the Moebius band due to the progressive change in fiber angulations, turning them from epicardial to endocardial.

It can be seen that the myocardial structure is not a mesh but a continuous muscle. (12) The mesh concept was developed by segment overlap due to the folding of the myocardial helix.

A histological analysis of the trigones has also been performed, trying to find cardiomyocytes in them, as a possibility of myocardial insertion into these structures. Only collagenous tissue without cardiomyocytes was observed in our investigation of the trigones, confirming that the fulcrum is the support of the cardiac muscle, both at its origin and its end.

The myocardium cannot be anatomically suspended and free in the thoracic cavity because it would be impossible for the heart to eject blood at a speed of 300 cm/s. There must be a point of attachment, which we found and called cardiac fulcrum. In this supporting point, the muscle fibers are inevitably obliged to intertwine with the fulcrum. In our anatomical and histological research, the connective, chondroid or osseus fulcrum showed this insertion, attaching the origin and end of the cardiac muscle.

In the fulcrum, the heart finds the fixed point enabling the mechanics of muscular torsion. The opposite rotation of the left ventricle from base to apex (13, 14) allows the development of elevated pressure which reduces tension, exactly as "wringing a towel". This mechanic, found in mice and humans, (15-18) helps the ejection of the blood content in a limited time span with the necessary force to circulate throughout the whole organism.

Limitations

There were few human specimens studied because it is difficult to have access to intact, well-preserved hearts for a careful dissection. We think that this work should be expanded with a greater number of human adult and specially children's hearts. Our investigation was limited to eight human and ten bovine hearts.

CONCLUSIONS

The cardiac fulcrum found in this anatomical research would help to clarify the supporting point of the myocardial band to complete its torsion function. Without its presence, the heart would not achieve its hemodynamic efficiency of pumping blood at a speed of 300 cm/s.

Conflicts of interest

None declared.

(See authors' conflicts of interest forms on the website/ Supplementary material)

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