ORIGINAL ARTICLE

Anatomical Investigation of the Cardiac Apex

Investigación anatómica del ápex cardíaco

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ABSTRACT

Background: Understanding cardiac anatomy is the key to solve unknown issues about its function. The continuous and helical myocardial structure plays a fundamental role in its torsion-detorsion motions. Does the apex, a constitutive part of the ventricle, have relevance in cardiac dynamics or is it simply a *cul-de-sac*? The aim of this study was to answer this question.
Methods. Four young bovine and four human hearts (two embryos and two adults) were used for the anatomo-histological studies. Two procedures were carried out for this investigation: a) the continuous myocardium unfolding to observe the fiber arrangement at the tip of the left ventricle, called the apical zone; and b) horizontal and longitudinal sections to study the structure of the apex. The horizontal sections were performed between the middle 2/3 and the apex, and the longitudinal ones, sectioning left ventricular apex, with an apex-base orientation.
Results. In all the human and bovine hearts studied we found that the apex corresponds only to the left ventricle, where the twist of the descending segment is located, in the ascending continuity of the myocardium. The apical *cul-de-sac* has practically no muscular plane at its end. It is internally lined by the endocardium and externally by the epicardium. The muscular plane has only 10% thickness of the adjacent myocardium, a structural concept confirmed by transillumination.
Conclusions. The apex is a *cul-de-sac* practically devoid of muscle, in which the endocardium and epicardium are attached, but which performs the functions of supporting intraventricular pressures and being a constitutive part of the torsion and detorsion motions.

Keywords: Anatomy and histology - Myocardium - Heart Ventricles - Ventricular Function

RESUMEN

Objetivo: Comprender la anatomía cardíaca es la clave para resolver incógnitas sobre su función. La estructura miocárdica continua y helicoidal desempeña un papel fundamental en los movimientos de torsión-detorsión. El ápex, parte constitutiva del ventrículo, ¿tiene relevancia en la dinámica cardíaca o es simplemente un fondo de saco? El objetivo del presente trabajo fue responder este interrogante.
Material y métodos: Se utilizaron para los estudios anátomo-histológicos cuatro corazones de bovinos jóvenes y cuatro corazones humanos (dos embriones y dos adultos). Para esta investigación se realizaron dos procedimientos: a) desplegamiento del miocardio continuo para observar la disposición de las fibras en la punta del ventrículo izquierdo, denominada zona apexiana; b) cortes horizontales y longitudinales para estudiar la estructura del ápex. Los primeros se realizaron entre los 2/3 medio y apexiano, y los longitudinales seccionando la punta ventricular izquierda con una orientación ápex-base.
Resultados: Hemos encontrado en todos los corazones humanos y bovinos estudiados que el ápex corresponde únicamente al ventrículo izquierdo, en donde se ubica el giro del segmento descendente en la continuidad ascendente del miocardio continuo. El fondo de saco apexiano no posee prácticamente plano muscular en su extremo final. Está tapizado por dentro por el endocardio y por fuera por el epicardio. El plano muscular es apenas un 10% en espesor del miocardio contiguo. La transiluminación reafirma este concepto estructural.
Conclusiones: El ápex es un fondo de saco prácticamente sin músculo, en el que el endocardio y el epicardio se hallan adosados, pero que cumple funciones del soporte de las presiones intraventriculares y es parte constitutiva de los movimientos de torsión y detorsión.

Palabras clave: Corazón/anatomía & histología - Miocardio - Ventrículos cardíacos - Función ventricular

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INTRODUCTION

In light of current investigations (anatomical, histological, echocardiographic, magnetic resonance imaging and electrophysiological studies), the classical structural concept of the heart does not justify its mechanics. It is therefore essential to discern its true internal anatomy, understanding that identifying the structure leads to know the function. (1-6)

Recent investigations allow defining the myocardium as a single muscle which in its longitudinal continuity adopts a spiraling spatial arrangement, inserted at its ends (origin and end) in an osseous-chondroid-tendinous nucleus called cardiac fulcrum. (7,8). It thus limits the two ventricular chambers, the left one with an ellipsoid geometry and the right one with a semilunar shape. Torrent Guasp's cord model describes this spatial arrangement (Figure 1). (9,10)

In this structure, the apex presents characteristics different from those established in the historical process. Ventricular apex was classically considered a muscular *cul-de-sac*, continuous with the myocardium, assumed as completely homogeneous. This interpretation does not correlate with the current myocardial structure concept of a continuous, longitudinal muscle, spatially arranged as a helix, which by twisting at the apical level, due to the spiral geometry it adopts, must practically lack any muscle at that point.

Consequently, we have investigated the anatomical-histological structure of the apical myocardial zone, with the aim of describing its structural reality, also correlating it with some already studied and published functional parameters. (6-11)

METHODS

Eight hearts were used to carry out the anatomo-histological studies: four young bovine hearts (800-1000 g) and four human hearts (two from 16- and 23-week embryos and two adult hearts with average weight of 300 g) obtained from the morgue and the slaughter house. The following procedures were carried out for this investigation:

a) Unfolding of the continuous myocardium to observe the fiber arrangement at the tip of the left ventricle, called the apical zone; b) horizontal and longitudinal sections to observe the apex arrangement. The horizontal sections were performed between the middle 2/3 and the apex, and the longitudinal ones sectioning the apex with an apex-base orientation. (Figure 2) ´

The prior preparation of the heart to achieve the continuous myocardium unfolding has already been explained by the authors in previous publications. (8)

RESULTS

The apex -only formed by the left ventricle- is a zone placed at the twist of the descending segment as it becomes the ascending segment in the myocardium continuity (Figure 1). In this helical shift of its fibers, which turn from subepicardial into subendocardial (Figure 3), a spiral of circularly interwoven muscle layers is formed, limiting a duct, more virtual than real, since the systolic contraction narrows it as it does with the mitral orifice

At this level, the apex presents 90% thinning in relation to the adjoining myocardium. The abrupt change in direction allows the continuity of the descending segment to become the ascending segment and represents the complete proof of the helical myocardial arrangement (Figure 4). In the apex, remnant fibers of the muscular vortex slide between its

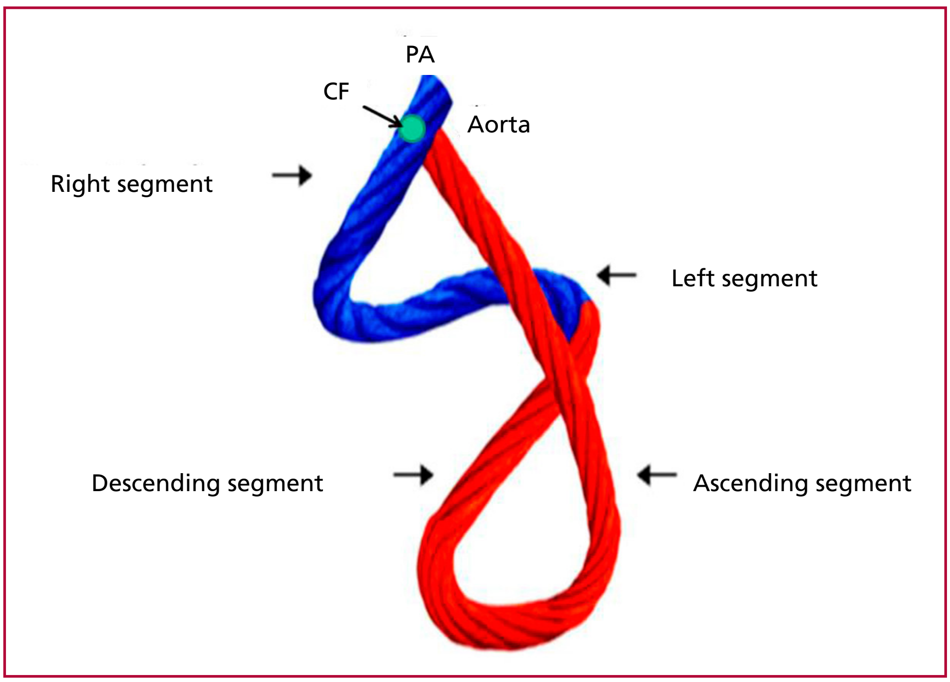

Fig. 1. Cord model of the continuous and helical myocardium describing the different segments that form it. In blue: basal loop. In red: apical loop. CF: Cardiac fulcrum, where the fibers insert at the beginning and end of the continuous myocardium

circular margin. It is a thin reinforcement in bovine and human myocardium, both in embryo and adult hearts. Thus, the apical *cul-de-sac* has practically no muscular plane at its end, and is lined internally by the endocardium and externally by the epicardium, an anatomical arrangement that can be verified by transillumination (Figure 4). Transverse sections evidence this spiraling shift of the fibers as they reach the apex (Figure 3), while longitudinal sections determine its almost complete lack of muscular plane (Figure 4).

DISCUSSION

The main consideration is that in the apical zone the fibers of the continuous myocardium undergo a helical swirl motion, with sphincter-like arrangement as they transform from subepicardial into subendocar-

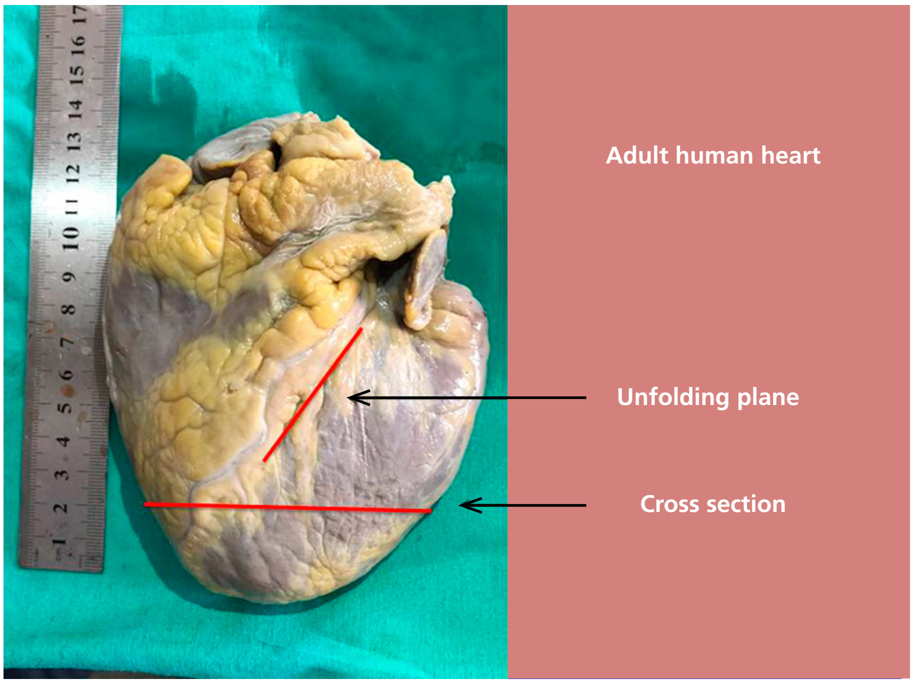

Fig. 2. Unfolding plane and horizontal section performed in the investigation (adult human heart).

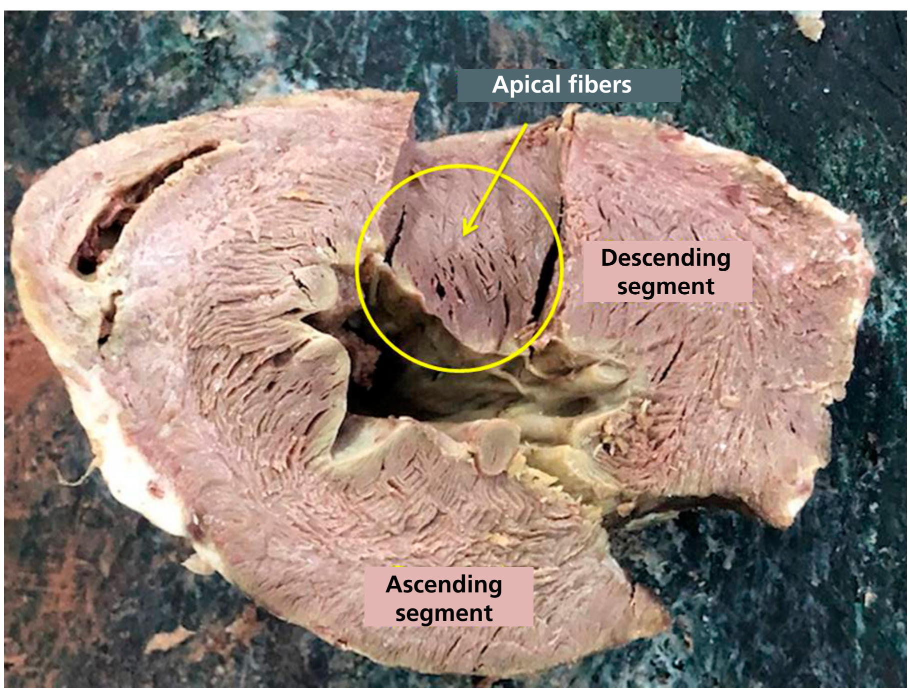

Fig. 3. Apical fibers. Note the fiber shift as they near the left ventricular apex.

dial fibers, overlapped like the tiles of a roof.

In the external wall of the distal part of the descending segment, when it twists at the apical level and becomes ascending segment, the cardiomyocytes evidence a dissimilar architectural orientation to that of the internal surface in planimetric sections, the only site of the continuous myocardium segments where this situation occurs (Figure 5). The rest of the arrangement is always parallel. This resembles the Moebius band, given the progressive change in fiber angulation that transforms them from epicardial into endocardial fibers.

Of the three turns made by the descending band in relation to the ascending band (Figure 1), a situation that is confirmed when unfolding the continuous and helical myocardium, the first two successively pass anteriorly and posteriorly. The last step, is again posterior. (6,11) In this interplay of the base and the

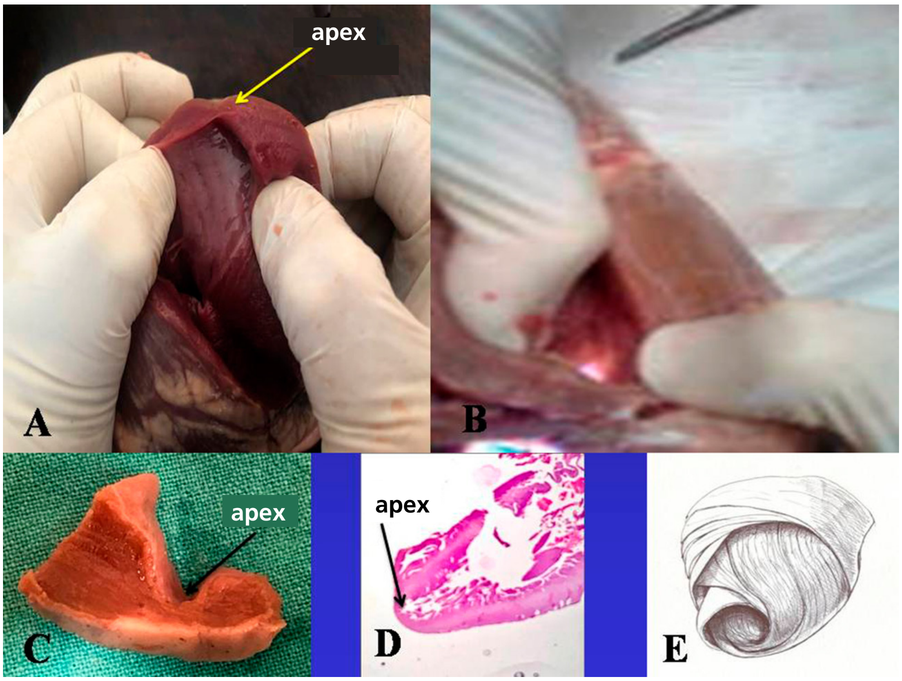

Fig. 4. A: Cardiac apex. **B:** Positive transillumination in the apical *cul-de-sac* shows that there are practically no muscle fibers in this region. **C** and **D:** Macroscopic and microscopic detail of the apex showing the endocardium attached to the epicardium, almost devoid of a muscular layer, with 10% thickness relative to the contiguous myocardium. **E:** The drawing of the helically coiled continuous myocardium reveals the nature of the apex, formed by a fragile zone given the change in orientation of the descending into ascending segment. **A** and **B:** bovine heart. **C:** adult human heart. **D:** 16-week human embryo.

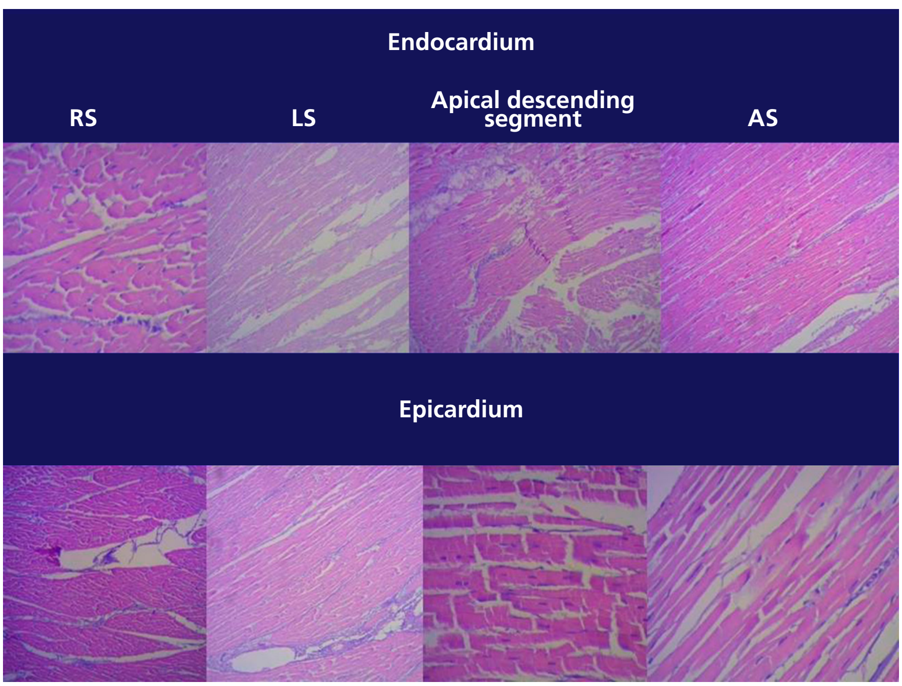

Fig. 5. Segmentary sequence of the histological analysis of the continuous myocardium. Hematoxylin-eosin technique (15x). **RS**: right segment; **LS**: left segment; **AS**: ascending segment.

apex, after a short counterclockwise rotation, an opposite rotation occurs between them, as it continues to be counterclockwise in the apex, but changes to a clockwise orientation at the base (heart seen from the base).

The prolongation of the descending band with the ascending one is a continuum that allows in the vertex the apical loop to act as a bellows that shortens in systole and lengthens in the protodiastolic (suction) phase. An expression of this anatomical-functional process is an apical zone with the ability of facilitating the cardiac base motion towards the apex during systole (shortening) and its retreat during suction, achieving ventricular lengthening. At this point we consider that by passing two consecutive times behind the ascending band, the descending band prevents part of the cardiac volume (30% of the total diastolic volume) to be ejected at end-systole, remaining as residual volume. This remnant volume has the function of a "limiting layer" for correct suction during the protodiastolic phase, avoiding the need of generating an important energy expenditure to perform ventricular suction, which would occur if the ventricular walls were closely attached.

Strictly speaking, the apex makes almost no measurable displacement. It remains practically immobile during the entire cardiac cycle, exerting only a certain pressure on the ribcage (apex beat). It is the base of the heart that makes the motions by descending (systole) and ascending (suction). Thus, despite the classical concept of apex beat against the thoracic wall, its length shortens owing to the descent of the cardiac base simultaneously with its counterclockwise rotation The apex is subjected to a final pressure in its *cul-de-sac* at the time of aortic valve closure. When blood is ejected from the heart, it undergoes a retropropulsion motion in systole, a principle of action and reaction enunciated by Newton's third law, with the apex as the main tributary of the retrograde force suffered by the ventricular cavity. This movement of blood against the *cul-de-sac* explains the "beat" perceived in the ribcage. High percentage of ventricular wall aneurysms, as well as congenital ones, are generated in the apical zone and the anterior wall. In congenital aneurisms, the area attached to the left ventricle is wide; histologically they lack a myocardial muscular layer and present a single wall of fibroelastic, sometimes calcified, tissue. (12)

The apical *cul-de-sac* has been used in the ellipsoidal reconstruction technique of the left ventricle. (13,14) The incision, entering through the vertex and oriented parallel to the anterior descending artery, acts on the area limited by the descending and ascending segments of the myocardial band, corrects the distortion of the septum and allows the surgery to be performed by entering through the avascular left ventricular wall, avoiding the arterial system to be pulled during the resection. The technique of suturing the external borders by overlapping them generates a geometric flap effect reinforcing the apex, an especially vulnerable area in cardiac dilation. Both the original incision and the size of the flaps must consider the dilation of the ventricle or cavity to be preserved, in order to reduce the increased ventricular volumes. This technique is enabled by the apical conformation, avascular and almost without muscle.

The essential fact of cardiac mechanics is that the basal and apical muscle fibers move in opposite senses. This disparity in direction correlates with the trajectories attained by the fibers and the helical pattern of the anisotropic cardiac myocardium that limit the ventricles.

CONCLUSION

At the distal end of the left ventricle, the apex surrounds a virtual conduit with almost no muscular plane at its end, internally lined by the endocardium and externally by the epicardium, practically with no intermediary functional muscle. It is essential to consider that in the apical zone the fibers undergo a helical swirl motion with sphincter-like arrangement as they transform from subepicardial into subendocardial fibers.

The apex (space between the descending and ascending segments forming the apical loop), has in normal conditions the faculty of annular narrowing (sphincter-like mechanism) to support the retrograde intracavitary pressure, produced by blood ejection.

The apex should be considered as a duct with a muscular border surrounding its entire ring, while at the ventricular base this ring has two parts, one corresponding to the left ventricular free wall and the other to the interventricular septum. In addition, the most superficial basal fibers make contact, without inserting, with the fibrous mitral annulus, a situation absent at the apical level. The essential functional difference between basal and apical regions is the opposite fiber shift (12,16-19). This characteristic allows the work of myocardial torsion to achieve cardiac blood ejection and the subsequent detorsion that generates suction and diastolic filling.

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