Ventricular Myocardial Sheet

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ABSTRACT

Background: Despite the fact that the exact architecture and orientation of ventricular myocardium are critical to cardiac functions either in health or disease, it is still debated.

Objectives: Anatomical demonstration of the ventricle myocardium (VM)as a single, long and continuous muscular sheet and this muscular sheet can be dived into 3-segments. As a new anatomical concept the left ventricle is a triple layers wall; whether the right ventricle is a single layer wall.Histological demonstration of different directions of muscle-fibers at each layer of ventricular myocardium.

Type of the study: Cross- sectional study.

Methods: In this study 100-heart (fish, chicken, goat, sheep and cow) were dissected and analyzed. Dental lacrona and wax knife used majorly in the dissection, boiling of the hearts with distilled water and finally opening them by the "opening-technique".

Results: Ventricular myocardium is a single, long and continuous muscular sheet in 100-samples of different species which had been included in the study (passing from the fish toward the cow). VMS can be divided into 3-segments in (100% of cow, 95% of goat and 85% of sheep). The left ventricle is a triple layers wall; whether the right ventricle is single layer wall, this result observed in (100% of cow, 95% of goat and 85% of sheep).Finally different directions of muscle fibers observed at each layer of ventricular myocardium where the subendocardial layer shows transverse running pattern of muscle fibers, mesocardial layer shows longitudinal running pattern of muscle fibers and subepicardial layer shows mixed running patterns of muscle fibers.

Conclusion: Ventricular myocardium is single, long and continuous muscular sheet. This sheet consists of 3-segments. These segments coils in spiral track and form the triple layers left ventricular wall and the single layer right ventricular wall. By histological examination of ventricular myocardial layers different directions of muscle fibers observed at each layer.

Keywords: Torrent-Guasp, Ventricular ,myocardial.

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William Harvey realized more fully than any anatomist that "structure is a pure guide to function". Harvey was a student of Fabricius in Padua, who studied anatomy to determine the purpose of the various parts of the human body. Harvey fulfilled the terms of a ‘‘functional anatomist". These observations have enormous impact on the cardiac surgeon, because rebuilding the macroscopic structure/function relationship forms the infra- structure for our specialty. William Harvey dissected cadaver hearts and concluded that the heart squeezed by constriction to eject and dilated passively to fill. These basic concepts are the currently accepted mechanism of cardiac function, but they do not explain the twisting phenomena observed during emptying and filling of the viable beating heart that are seen during cardiac operations and that are now documented by magnetic resonance imaging (MRI) and speckle tracking echocardiography.[1, 2] Keith elaborated on the recognized physiologic cardiac function and presented a currently unfulfilled challenge by statin ‘‘we cannot claim to have mastered the mechanism of the human heart until we have a fundamental explanation of its architecture".[3] Different models had been developed through time by the worldwide anatomist (Figure 1, A, B, C) and most of these models had been emerged that ventricular myocardium in a coiled sheet or band.[4, 5, 6, 7, 8] Torrent-Guasp was the first anatomist who discovered the helical heart structure by simple hand-dissection. First, the heart was unraveled to identify an underlying mid ventricular spiral fold that changed the transverse fibers to an oblique configuration and that allowed the unfolded heart to become a simple flattened longitudinal rope-like model extending from the pulmonary artery to the aorta (Figure 1, D). Refolding the heart into its natural biologic configuration allowed the definition of 2-loops, termed the ‘‘transverse basal’’ and ‘‘oblique apical loops’’.[9, 10, 11]

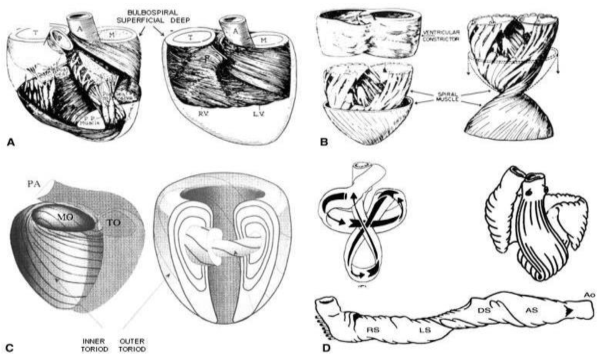


Figure 1. Examples of some models of myocardial fiber organization. A, Robb and Robb model. B, Rushmer's conceptual model. C, Streeter's LV model. D, Torrent Guasp model.

The anatomical and histological concept of ventricular myocardium slowly developed over centuries. Despite many difficulties, the anatomical and histological- field of ventricular myocardium slowly but steadily making progress. In the last 20-years multiple and new anatomical and histological concepts of ventricular myocardium developed and emerged by using modern imaging techniques rather than simple hand-dissection. In one of these techniques, high-spatial resolution contrast-enhanced (MRI) had been used and in which the layers of the ventricular myocardium chambers had been confirmed (Figure 2, A) (Figure 2, B).[12]

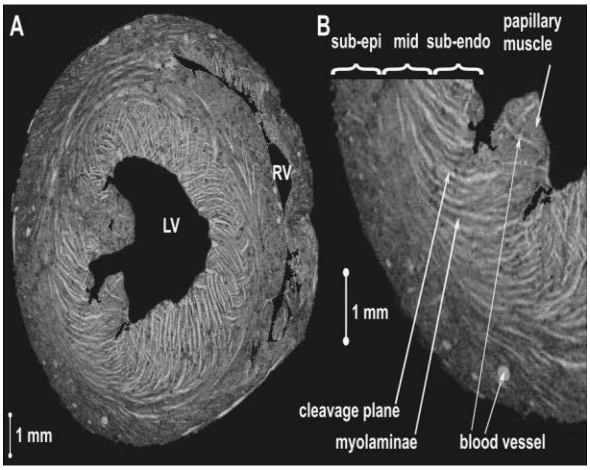


Figure 2. Laminar architecture in a near equatorial short-axis slice (MRI dataset C1HR, resolution of 25 25 37m).

Another technique which had emerged is diffuse tensor imaging (DTI), in which each layer of left ventricular wall have been observed and assorted according to its muscle fibers direction by using different color for each direction (Figure 3).[13]

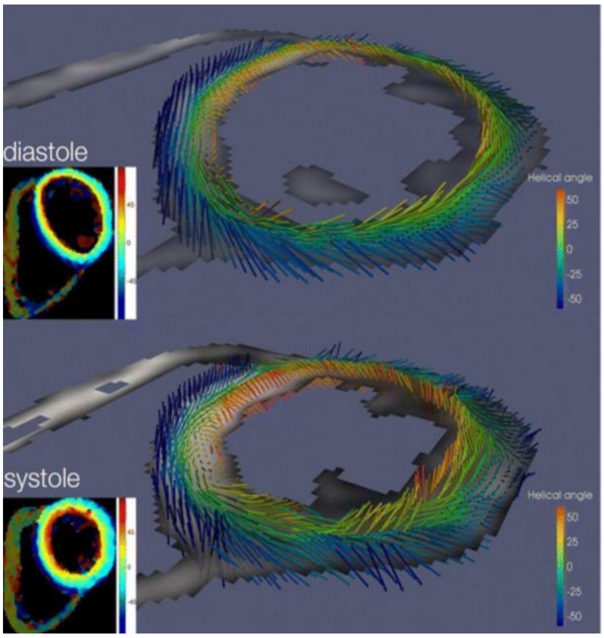


Figure 3. 3D representation of HA (primary eigenvector) in diastole and systole showing a progression of myocytes from a left handed helix in the epicardium (blue), to circumferential in the mesocardium (green) to a right handed helix in the endocardium (red-yellow).

Some investigators have tried to provide functional evidence that would necessarily imply the presence of a functional band. Thus, several investigators used different techniques to try to provide evidence of this sequential contractale band. In one of these investigations, sonomicrometry had been used to establish this sequence by measuring the start of contraction at 4 points in the ventricular myocardium, identifying them with 4 matching points along the muscle band trajectory) (Figure 4).[14]

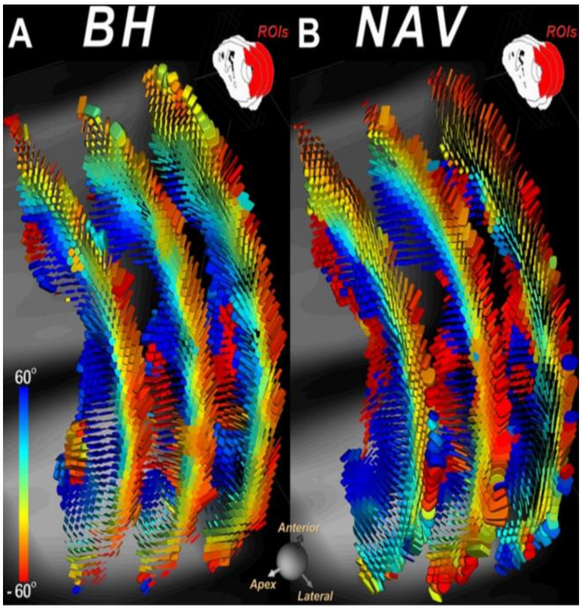


Figure 4. Experiments in open-chest pigs (n=32). The illustrations at the top show the uncoiled myocardial band according to Torrent Guasp. The points marked (p) show where the pairs of ultrasonic crystals have been implanted, following the direction of the fibers. The graph at the bottom shows mean (standard error) values for the times of onset of contraction at the points described above. The subpulmonary area and left ventricular free wall are the areas with the earliest contraction, followed by the mesocardium on the anterior aspect of the apex, which corresponds to the descending segment of the band. Finally, the epicardium contracts on the anterior aspect of the left ventricle corresponding to the ascending segment of the apical loop (own unpublished data).

Finally the PGSE approach is applied over a single heart beat and can be easily combined with a free-breathing acquisition using a diaphragmatic navigator. The use of a free-breathing navigator-based acquisition with the STE sequence is unfortunately more complex. Motion compensation in the STE approach assumes that all motion is periodic and identical from beat to beat. However, even if a narrow navigator window is used, the motion of the diaphragm and hence the heart can violate these conditions, leading to signal loss. In addition, the use of three excitation pulses over two successive heartbeats does not render the technique suitable for slice tracking. Nevertheless, navigator-based STE has been successfully performed, albeit with limited heart coverage, in normal volunteers (Figure 5).[15]

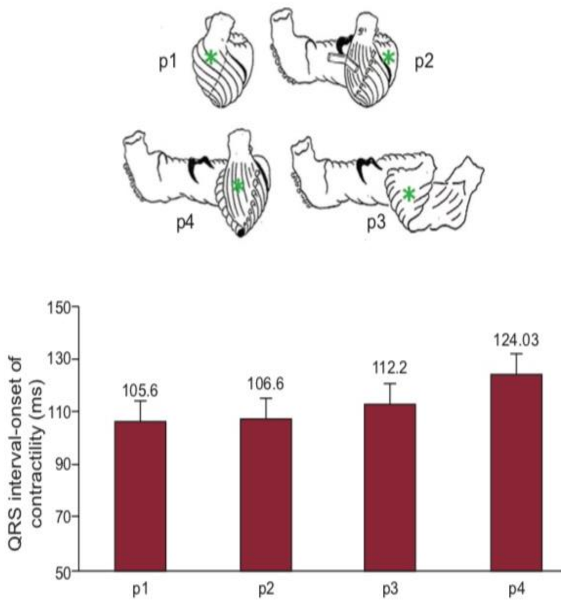


Figure 5. DTI of a healthy volunteer with STE approach using (A) multiple breath-holds (BH) and (B) a diaphragmatic navigator (NAV) during free breathing. In both cases, the identical three short-axis slices were imaged and the tensor field was represented with superquadric glyphs color coded by HA. The qualities of the BH and NAV approaches appear fairly similar.

Methods: Macroscopically (Anatomically): In this study 100-heart (fish, chicken, goat, sheep and cow) were dissected and analyzed (Figure 6).

Figure 6. Multiple hearts of different species (fish, chicken, sheep, goat and cow); which included in the study.

Figure 7. Dissection equipments

The equipment; which used in the dissection were Dissection scissor, dissection scalpel, wax knife and dental lacrona (avoid the use of sharp dissection scalpel because they may distort the architecture of myocardium) (Figure 7) .Starting by the removal of atria, parts of aorta and pulmonary artery (in order to expose the ventricles only) by using dissection scissor then remove the visceral-pericardium and pericardial-fat by using wax knife and dental lacrona (in order to expose the ventricular myocardium) (Figure 8).By simple boiling with distilled water approximately 1-3h .according to the size of the heart (1-1.5h for fish, chicken, small sheep and goat heart and 2.5-3h for cow, large sheep and goat heart). The method of simple boiling is the same method that used by Torrent-Guasp.[16]Carrying out the heart from the boiled water into a thick peace of paper in order to get dry (this will make the opening-technique easier).By using the dissection scalpel make a transverse section passing throw the base of the heart, now you are able to visualize the cavity of each ventricle; where each surrounds by its wall, if you look closely to the wall of each ventricular cavity you will visualize that the right ventricle wall is represented by a single relatively thin layer in contrast to left ventricle wall which represented by a deep thick layer covered with a thin layer (Figure 9).

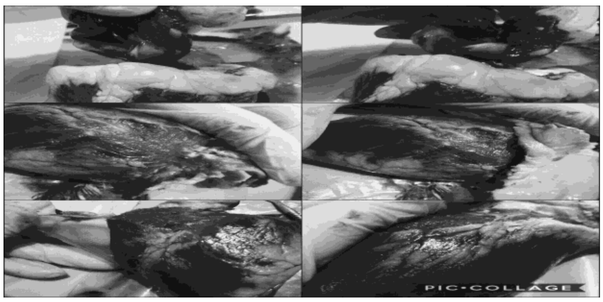


Figure 8. The reomval-procedure of atria, parts of aorta with parts of pulmonary artery and viscera pericardium with pericardial fat.

Figure 9. A transverse section passing throws the heart base, showing the layers of left ventricular wall and right ventricular single layer wall.

Use the visualized layers of the ventricular wall layers plus the anterior and posterior inter-ventricular sulcus as guiding marks for the “opening-technique” of the ventricular myocardium.Opening-technique should carried out gently by your naked fingers only (your nails is your dissection blade). The opening-technique is very similar to Torrent-Guasp method but it is different in the finding of new layers and segments of the ventricular myocardium.[17, 18]Gently make a fissure with your naked fingers along the lateral border of the anterior inter-ventricular sulcus (Figure 10, A).Now the cavity of the right ventricle is opened (notice the right ventricle wall is a single relatively thin layer wall) (Figure 10, B) (Figure 10, C).Dig with your naked fingers beneath the posterior inter-ventricular sulcus (always digs from the base toward the apex) (Figure 10, D).Continuous the digging toward the anterior inter-ventricular sulcus again in order to free the external thin layer of left ventricle wall ”let’s called it layer-1 of left ventricle” (notice that the single thin layer of right ventricle wall continuous as the external thin layer of left ventricle wall) (Figure 10, E) (Figure 10, F).

The hardest-point in opening-technique is to visualize the middle thin layer of the left ventricle wall; it is a thin layer continuous along with layer-1 and internal to It and also; it adheres internally to the thick layer of left ventricle wall ”let’s call it layer-2 of left ventricle” (I visualize this layer hardly after sample No.9).

Dig toward the posterior inter-ventricular sulcus again in order to Free layer-2; which lays along with and internal to layer-1 (it usually adheres externally to the first layer to form a false single layer and adheres internally to the thick layer of left ventricle) (Figure 10, G).Now all what remain is the internal thick layer of left ventricle coils around its self (notice that layer-1 continuous as the internal thick layer of left ventricle wall).

Open this coiled internal thick layer by making a fissure with your naked fingers along its connection line this line is parallel and posterior to the posterior inter-ventricular sulcus (Figure 10, H).Ventricular myocardial sheet now well visualize as single, long, continuous and crescentic muscular sheet (Figure 10, I).

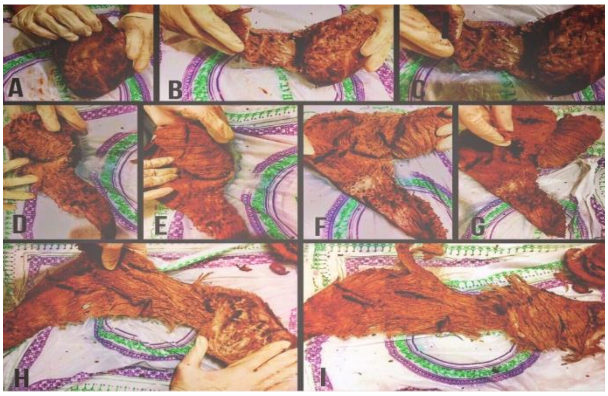


Figure 10. The "opening-technique” of ventricular myocardium.

Microscopically (Histologically)
Type of section:- transverse
Type of specimen:- cow-heart
Site of section:- base of the (cow-heart)
No. of sections:- 6
Name of sections:- subenoardial section, mesocardial section, subepicardial section (septal), subepicardial section (pure), right ventricle section and total left ventricle section.
No. of slices:- 24 (4-slices from each section)
Type of stain:- H&E stain
No. of slides:- 7-slides

AIM OF THE STUDY:

- To approve that ventricular myocardium is a single and continuous sheet and this sheet can be divided into segments and also adding a new anatomical-concept about the myocardium architecture of the ventricular chambers.
- To explain the different directions of muscle fibers of ventricular myocardium histologically.

Results:MACROSCOPICALLY (ANATOMICALLY)*:* IN THIS STUDY 100-HEART (FISH, CHICKEN, GOAT, SHEEP AND COW) WERE DISSECTED AND ANALYZED (FIGURE 6).

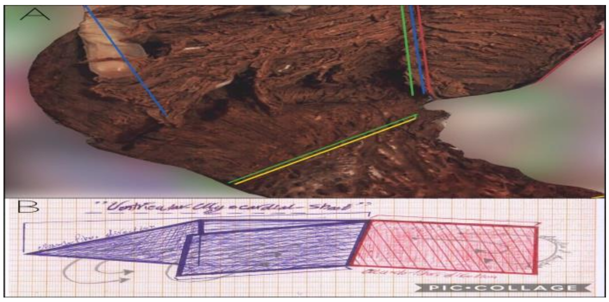


Figure 11. A, VMS-segments in cow heart. Showing the subendocardial segment between red lines, mesocardial segment between blue lines, proximal part of subepicardial segment between green lines and distal

part of subepicardial segment between yellow lines. B, VMS-segments graph. Showing the subenodcardila segment in red color and mesocardial with subepicardial segments in blue color.

- Ventricular myocardium is a single, long, continuous and crescentic muscular sheet". This result observed in 100-samples of all the species; which had been included in the study (passing from the fish toward the cow).
- "Ventricular myocardial sheet can be divided into 3-segments". This result described in (Table-1).

Table 1. Difference in the number of VMS-segments in different species.

Type of species	No.samples	2-segments VMS	%	3-segments VMS	%
Fish	20	20	100	0	0
Chicken	20	2	10	18	90
Sheep	20	3	15	17	85
Goat	20	1	5	19	95
Cow	20	0	0	20	100

*VMS consists of 2-segments in (10% of chicken, 15 of sheep% and 5% of goat) may be due to Poor observation, congenital anomaly and developmental variations.

VMS-segments :Subendocardial-segment: A thick muscular segment (the thickest segment) with grossly oblique muscle fibers direction. It begins from aorta and ends at the transitional line between the oblique and transverse muscle fibers (this segment localize between the two red lines). Mesocardial and subepicardial segments emerge together from the ending site of this segment (Figure 11, A) (Figure 11, B).

Mesocardial-segment: A thin muscular segment (the thinnest segment) with grossly almost transverse muscle fibers direction. It begins from the ending site of subendocardial segment and ends at the site of posterior inter-ventricular sulcus (this segment localize between the two blue lines) (Figure 11, A) (Figure 11, B).

Subepicardial-segment: A thin muscular segment with grossly almost transverse muscle fibers direction. It begins from the ending site of subendocardial segment and ends first at the site of posterior inter-ventricular sulcus to form left ventricle part (this part localize between the two green lines) and second at the site of anterior inter-ventricular sulcus to form right ventricle part (this part localize between the yellow lines) (Figure 11, A) (Figure 11, B).

- "The left ventricular-wall consists of 3-layer; whether the right ventricular-wall consists of a single-layer". This result described in (Table-2).

Table 2. Difference in the number of VMS-layers in different species.

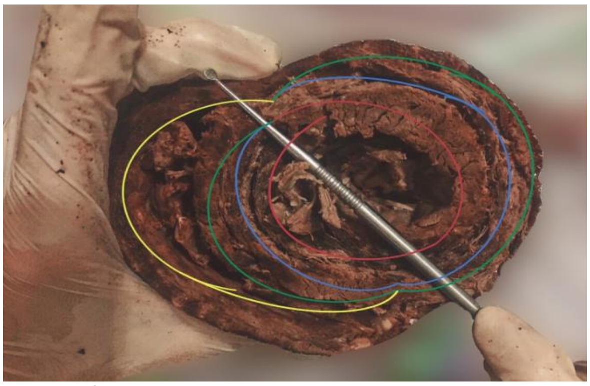
Type of species	No.samples	2-layers VMS	%	3-layers VMS	%
Fish	20	20	100	0	0
Chicken	20	2	10	18	90
Sheep	20	3	15	17	85
Goat	20	1	5	19	95
Cow	20	0	0	20	100

*VMS consists of 2-layers in (10% of chicken, 15% of sheep and 5% of goat) may be due to Poor observation, congenital anomaly or developmental variations).

VMS-layers:Subendocardial-layer: A thick muscular layer (the thickest layer) with grossly oblique muscle fibers direction (red circle). It forms by the coiling of the subendocardial segment around the cardiac axis (Figure 12).

Mesocardial-layer: A thin muscular layer (the thinnest layer) with grossly circular muscle fibers direction (blue circle). It forms by the coiling of mesocardial segment around the cardiac axis (Figure 12).

Subepicardial-layer: A thin muscular layer with grossly oblique muscle fibers direction. It forms by the coiling of subepicardial segment in contra clock-wise manner. It can be divided into left ventricle part (green circle) the



part that form the subepicardial layer

Figure 12. VMS-layers in cow heart. Showing subendocardial layer in red color, mesocardial layer in blue color, proximal part of subepicardial layer in green color and distal part of subepicardial layer in yellow color.

of left ventricle and right ventricle part (green circle) the part that form the single-layer wall of right ventricle (Figure 12).

Microscopically (Histologically):"Different directions of muscle-fibers had observed microscopically at each layer of ventricular myocardium". This result described in (Table-3).

Table 3. Difference in the muscle fibers direction of VMS-layers in the cow heart.

Section	No.slices	Longi. M.Fs	%	Trasy. M.Fs	%	Mix.	%
Subendo.	4	0	0	4	100	0	0
Mesocard.	4	4	100	0	0	0	0
Pure subepi.	4	0	0	0	0	3	75
Septal subepi.	4	0	0	0	0	4	100
RV	4	0	0	0	0	3	75

__VMS-layers :__**Subendocardial-layer:** In this layer muscle fibers showing transverse running pattern (Figure 13, A).

Mesocardial-layer: In this layer muscle fibers showing longitudinal running pattern (Figure 13, B).

Subepicardial-layer: In this layer muscle showing mixed (longitudinal and transverse) running pattern (Figure 14) (Figure 15). This mixed pattern extended from the epicardium into the mesocardial layer. The running pattern of muscle fibers is the same at left ventricle part (left ventricle subepicardial layer) as well as at its right ventricle part (right ventricular wall).

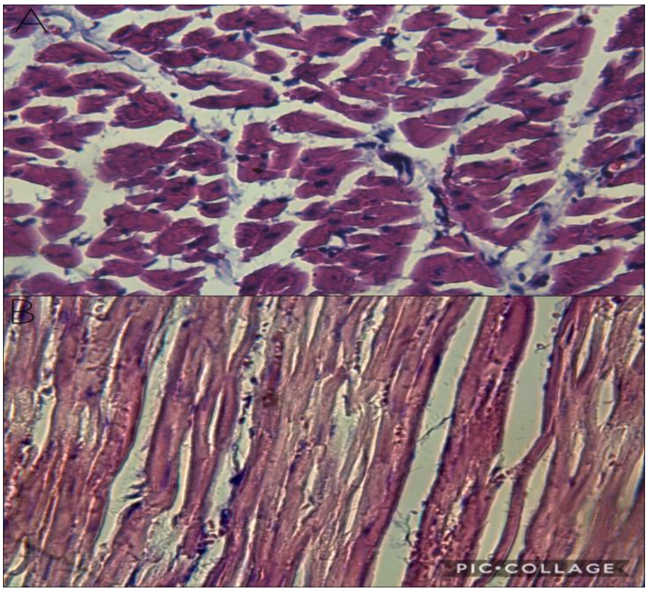


Figure 13. A, subendocardial section showing the subendocardial-layer with transverse running pattern of muscle fibers. B, mesocardial section showing the mesocardial-layer with longitudinal running pattern of muscle fibers.

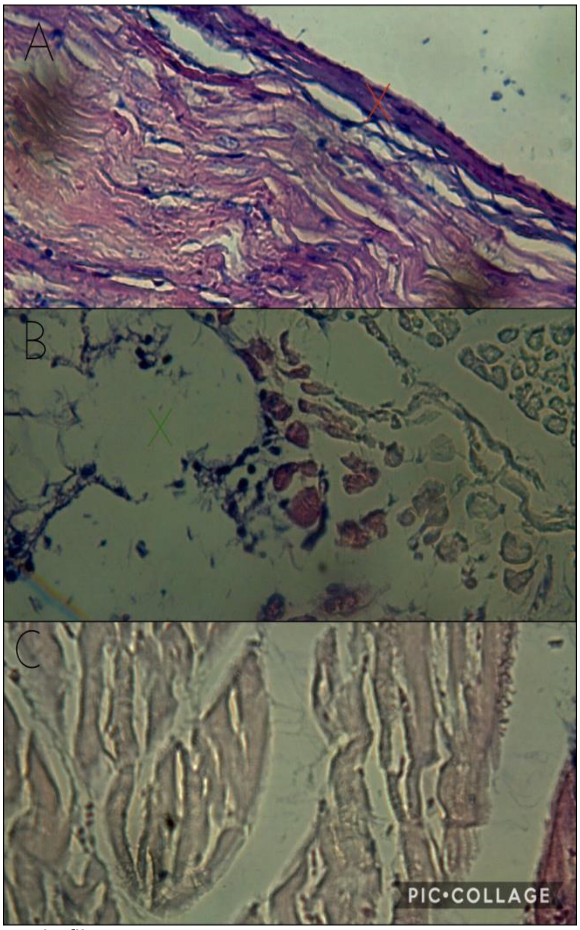


Figure 14. Proximal subepicardial section. A, showing transverse running pattern of muscle fibers near the endocardium (red x). B, showing longitudinal running pattern of muscle fibers near the epicardium (green x). C, showing mixed running pattern of muscle fibers in the center of the subepicardial layer.

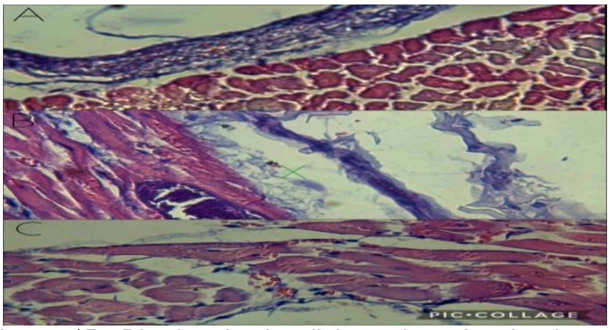


Figure 15. Distal subepicardial section. A, showing transverse running pattern of muscle fibers near the endocardium (red x). B, showing longitudinal running pattern of muscle fibers near the epicardium (green x). C, showing mixed running pattern of muscle fibers in the center of the subepicardial layer.

Discussion

Macroscopically (Anatomically): In this study we demonstrated that the ventricular myocardium is a single, long, continuous and crescentic muscular-sheet in 100-samples of all the species; which had included in the study (passing from the fish toward the cow). This result supported by the dissection studies of Torrent-Guasp[18] ; who said that “I was able to conclude that the ventricular myocardium consists of a single muscle band, which starts at the origin of the pulmonary artery and finishes at the root of the aorta”. In this study we also; demonstrate that ventricular myocardial sheet can be divided into 3-segments in 72 samples of all the species (100% in cow, 95% in goat and 85% in sheep); which had been included in the study (passing from the fish toward the cow) (Table 1). This result “emerge a new concept of ventricular myocardial segmentation”. This result did not emerge in any previous study, this concept clarified the ventricular myocardial architecture by stating that “VMS can be divided into 3-segments and these segments coil in spiral track in order to form ventricular myocardial-architecture”. In this study finally we demonstrated that “the left ventricular-wall is a triple layers wall; whether the right ventricular-wall is a single-layer wall” in 72-samples of all the species (100% in cow, 95% in goat and 85% in sheep); which have been included in the study (passing from the fish toward the cow) (Table 2). This result supported by a recent study used diffusion MRI in rat, sheep and human hearts; which done by Choukri Mekkaouia, Timothy G. Reesea, Marcel P. Jackowskib, Himanshu Bhatc and David E. Sosnovika. This study demonstrated that “the left ventricle consisted of subendocardial thick layer, mid myocardial thin layer and subepicardial thin layer (triple layers wall)” by using diffusion MRI in rat, sheep and human.[15] Another recent study used DTI in porcine heart[19] ; which done by Martijn Froeling, Gustav J. Strijkers, Aart J. Nederveen, Steven A. Chamuleau, Peter R. Luijten. This study demonstrated that “the heart consists of outermost subepicardial layer, innermost subendocardial layer (-60^{o}, 60^{o} variation) and circular mesocardial layer between them”

Microscopically (Histologically): In this study we demonstrate that different directions of muscle-fibers had observed microscopically at each layer of ventricular myocardium. This result supported by a microscopical study done by Zienab A. Gouda, Yaser Hosny Ali Elewa and Assmaa O. Seliml. They said that “the running pattern of cardiac myofibers in LV wall at different levels from beneath atrium to apex of the heart with several histological characteristics. This different running patterns of the cardiac myofibers among different levels as well as, within the same level from sub-epicardial to the endocardial region might indicate multiple rolling of the cardiac myofibers”.[20, 21, 22]

Conclusion: In this study, we revealed that ventricular myocardium is a single, long, continuous and crescentic muscular-sheet. This muscular sheet (VMS) can be divided into 3-segments and these segments are the thickest subendocardial segment, the thinest mesocardial segment and the relatively thin subepicardial segment (the subepicardial segment can be divided into proximal part and distal part). Furthermore, we revealed that VMS-segments coils in spiral track in order to form a triple layers left ventricular wall and a single layer right ventricular wall. The subendocardial segment coils and forms the inner most subendocardial layer, the mesocardial segment coils and forms the intermediate mesocardial layer and the proximal part of subepicardial segment finally coils and forms the outer most subepicardial layer where the distal part of it coils and forms the single layer right ventricular wall. Finally we revealed that different directions of muscle-fibers had observed microscopically at each layer of ventricular myocardium. The subendocardial layer shows transverse running pattern of muscle fibers, the mesocardial layer shows longitudinal running pattern of muscle fibers and subepicardial layer shows mixed (longitudinal and transverse) running pattern of muscle fibers. This mixed pattern extended from the epicardium into the mesocardial layer. The running pattern of muscle fibers is the same at its proximal part (left ventricle subepicardial layer) as well as at its distal part (right ventricular wall).

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