Journal of Veterinary Science & Technology

Ghonimi et al., J Veterinar Sci Technolo 2014, 5:4
DOI: 0.4172/2157-7579.1000193

Research Article Open Access

Os cordis of The Mature Dromedary Camel Heart (*Camelus dromedaries*) with Special Emphasis to The Cartilago Cordis

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Abstract

The present study was performed to clarify the presence of the bony structure; os cordis and cartilage; cartilago cordis in the heart of the mature dromedary camel. This investigation was carried out on the heart of ten healthy mature camels. The heart of the camel contained only one bone. This bone is large, elongated and embedding inside the heart wall where the cardiac muscles are inserted and fixed. It is found mainly in the aortic ring; especially in the adjacent area between the aorta and the left & right atrium respectively. Moreover, it is lying in the atrioventricular plane near the junction of the interatrial and interventricular septa of the camel heart and extending anteriorly into the atrioventricular valve rings. Histologically, the os cordis appeared consisting of fibrous connective tissue, small foci and pieces of hyaline cartilage, calcified cartilage and large piece of spongy bone. The spongy bone appeared having red and white bone marrow with numerous RBCs, adipocytes and osteocytes. Moreover, the increasing of the calcified cartilage amounts and the development of bony structures in the camel heart skeleton are age dependent, which seems to be a sign of the over load of the mechanical forces and high pressure in the atrioventricular plane and the aortic ring of the heart during systole.

Keywords: Cardiac skeleton; Os cordis; Cartilago cordis; Heart bone; Calcified cartilage; Aortic ring; Camel heart

Introduction

The cardiac skeleton is the dense fibrous connective tissue into which the cardiac muscle fibers insert, and from which the cardiac valves extend. It supports each of the heart valves. Cardiac skeleton forms three types of structures; rings called annuli fibrosi surround each valve, triangular patches called fibrous trigones fill the spaces between the rings and the septum membranaceum consists of extensions of the cardiac skeleton into the interatrial and interventrical septae [1]. Furthermore, the fibrous rings are mainly composed of interwoven bundles of collagen fibres with a few elastic fibres surrounding the atrioventricular openings and the openings of aorta and pulmonary artery. The fibrous trigones consist of areas of dense connective tissue between the aorta and the atrioventricular openings and are connected by the aortic-mitral curtain. The right trigone, together with the membranous septum, constitutes the central fibrous body. In certain mammalian species, the trigones contain fibrocartilage, hyaline cartilage, and even bony material. The latter forms a right and left cardiac bone (os cordis) related to the trigone between atrioventricular ostia and the aortic ostium, respectively. Moreover, the right cardiac bone is regularly larger than the left [2].

Dellmann and Eurell [3], Gartner & Hiatt [4], Samuelson [5], and Junqueira et al. [6] stated that the musculature of the atrial and ventricular walls is inserted into the cardiac skeleton which is made of three parts; the fibrous triangle (trigonum fibrosum), the fibrous rings (annuli fibrosi) and the septum membranaceum. The fibrous triangle (trigonum fibrosum), is the connective tissue that fills the space between the atrioventricular openings and the base of the aorta. The nature of this connective tissue is species and age dependent. It may be predominantly dense and irregular connective tissue in (pigs and cats), fibrocartilage in (dogs), hyaline cartilage in (horses) or bone in (large ruminants). Furthermore, the fibrous rings (annuli fibrosi), are composed of intermingling bundles of collagen and a few elastic fibers that surround the base of the aorta, pulmonary artery, and the atrioventricular openings. Moreover, the septum membranaceum, is the fibrous or membranous part of the interventricular septum, constituting the upper portion of the interventricular septum, and consists of collagen fiber bundles.

The heart skeleton of many species contains fibrous connective tissue, cartilage and in larger animals like cattle, sheep, goat and pig even bone [7]. It serves to stabilize the heart during contraction and relaxation, especially to act against deformation of the aorta. Pieces of cartilage were found in single otter hearts [8]. In most mammalian species the cardiac skeleton is composed of coarse collagen fibres, fibrocartilage, and pieces of hyaline cartilage. Bone, the os cordis, is a regular constituent of the ruminant heart. The cardiac skeleton of the otter (*Lutra lutra*) was composed of coarse collagen fibers with intercalated pieces of fibrous and/or hyaline cartilage, calcified cartilage, and lamellar bone with red or white marrow. Pieces of hyaline cartilage were not clearly defined: a perichondrial layer was missing and coarse connective tissue continuously transformed into fibrous and hyaline cartilage. In both sexes, increasing amounts of calcified cartilage and bone correlated with increasing age [7]. Moreover, Egerbacher et al. [7] described that the presence of bony material in the heart skeleton of the otter, a small mammalian species, indicating that differentiation of bone is not exclusively related to the size of the organ. Furthermore, Malik et al. [9], Mia [10], Schmack [11] and Nickel et al. [12] claimed that heart bones are constantly seen in large ruminants.

Daasch [13] clarified that in the pig heart, 2 pieces of cartilage were lying close to the fibrous ring of the aorta. They tend to calcify and ossify in animals aged more than 3 years. Moreover, cartilage was

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Received June 03, 2014; **Accepted** August 28, 2014; **Published** August 30, 2014

Citation: Ghonimi W, Balah A, Bareedy MH, Abuel-atta AA (2014) Os cordis of The Mature Dromedary Camel Heart (Camelus dromedaries) with Special Emphasis to The Cartilago Cordis. J Veterinar Sci Technol 5: 193. doi:10.4172/2157-7579.1000193

found in the dog heart skeleton [5] and also in other canidae and in felidae [14]. In addition, cartilage is present in the heart of mice and rats [15], rabbits [16], Syrian hamsters [17], and serpents [18]. Additionally, Benninghoff [19] describe a cartilage-like structure in the centre of the right fibrous trigone of the human heart.

Otherwise, Young [18] clarified that the cartilago cordis, a cartilaginous element present within the heart, has been found in a number of vertebrates. A cartilago cordis was found near the roots of the aortic trunk and pulmonary artery in eleven species of snakes. There is substantial variation in the size, shape, and precise location of the cartilago cordis. Moreover, he explained that the presence of a cartilago cordis does not correlate with body size, taxonomic relationships, or habitat preference. The cartilago cordis may simply represent an illustration of the potential for chondrification that is present in the connective tissue of the aorticopulmonary septum.

Murata and Yamadak [20] claimed that the glycosaminoglycans involved in the cartilage of the porcine heart. Furthermore, the cartilage of the porcine heart contained hyaluronic acid, chondroitin, chondroitin sulfate A and/or C and keratin sulfate. Meanwhile, James et al. [21] described that there is no central fibrous body between the atrial and ventricular septa of the sperm whale (Physeter macrocephalus) and the whale has no os cordis. Only the upper quarter of the interventricular septum is fully formed; below that there is only a thin layer of fatty connective tissue between the two ventricles. And also, they elucidated that absence of an os cordis or central fibrous body or strong attachment between the two ventricles may pose both electrophysiological and hemodynamic hazards when the whale is no longer in its normally buoyant aquatic environment. So, the whale seems to be the only exception in mammals as the absence of any bone and cartilage. Additionally, he claim that a central fibrous body is missing and stated that the whale heart as a whole was soft and flaccid. Moreover, Nawal, S.E.O Babiker et al. [22] illustrated that the heart of the dromedary camel contained only one bone (os cordis).

The aim of our investigation is to through more light on the fibrous skeleton of the camel heart (Camelus dromedaries) in order to establish fibrous connective tissue, cartilage or bone as a regular constituent within the camel heart.

Materials and Methods

Hearts of ten apparently healthy mature camels were collected from Zagazig slaughter house in Sharkia province for the histological studies. The specimens were immediately fixed in 10% buffered neutral formalin and decalcified using the most frequently chelating agent; Ethylene diamine tetra acetic acid (EDTA). Decalcification is a lengthy procedure, as bone pieces have to be left in the decalcifying agent for several days or even weeks, depending on the size of the bone to become softer for easily processing and embedding. The fixed and decalcified specimens were processed using the usual histological techniques; dehydrated in ascending grades of ethanol series, cleared in benzene and embedded in paraffin. 5-7 µm thick sections were prepared and mounted on glass slides. These are dewaxed in xylene, hydrated in descending grades of ethanol series and stained with Harris's hematoxylin and eosin (H&E) for routine histological studies [23]. The microphotography were taken using a digital Dsc-W 130 super steadycyper shot camera connected to an Olympus BX 21 light microscope.

Results and Discussion

The connective tissue skeleton of the heart is separating the atria from the ventricles, supplying and supporting the attachments for the heart valves. The heart skeleton of many species contains fibrous connective tissue, cartilage and even bone in the larger animals. It serves to stabilize the heart during contraction and relaxation, especially to act against deformation of the aorta. The heart of the camel contained only one bone (os cordis). This bone is observed large, elongated constant bone. It resembles the finger like projection that embedded inside the heart wall where the cardiac muscles are inserted and fixed. Furthermore, it is typically similar to the elongated bone that present in the dog penis; os penis somewhat with some curvature. It is found mainly in the aortic ring; especially in the adjacent area between the aorta and the left & right atrium respectively. Moreover, it is lying in the atrioventricular plane near the junction of the interatrial and interventricular septa of the camel heart and extending anteriorly into the atrioventricular valve rings. These findings are goes hand in hand with Nawal et al. [22] in camel who reported that the heart of the camel contained only one bone (os cordis). Also, the presence of bone in the heart is in agreement with Junqueira et al. [6] and Samuelson [5] who stated that the connective tissue skeleton within the heart may be predominantly dense and irregular connective tissue in (pigs and cats), fibrocartilage in (dogs), hyaline cartilage in (horses) or bone in (large ruminants). Moreover, this finding is in coincidence with Schmack [11] who stated that the heart bones are remarkable features of the bovine heart skeleton. There are two bones in the heart; the large one, right heart bone is 3-6 cm and the small one, left heart bone is 2 cm and both are in the aortic ring. Furthermore, the finding is in parallelism with Simic [14] who described that the os cordis is a large constant bone lying near the junction of the interatrial and interventricular septa of the beef heart and extending anteriorly into the atrioventricular valve rings. And also, this result is in parallelism with the finding that described after Egerbacher et al. [7] in the Otter (Lutra lutra) who described that the os cordis observed of a varying number of small ossified pieces in the atrioventricular plane. Such pieces of bones were found mainly in the area between the aorta and the left and right atrium respectively.

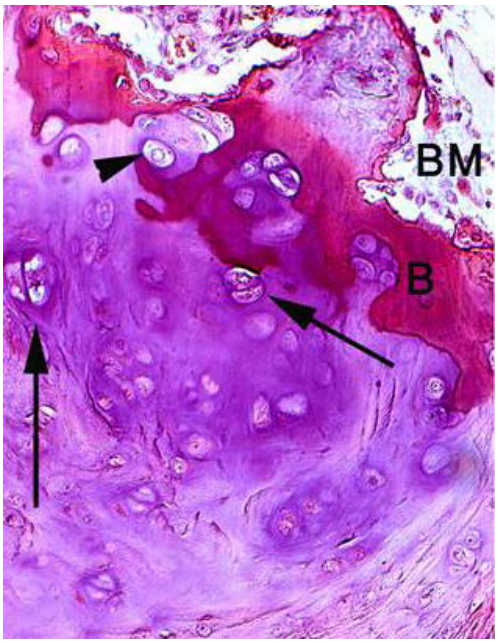

Figure 1: A photomicrograph showing the spongy bones (B), the calcified hyaline cartilage with chondrocytes nest (arrow), single chondrocytes (arrow head) and bone marrow (BM). Stain: H& E Obj.x 20: Oc.x10.

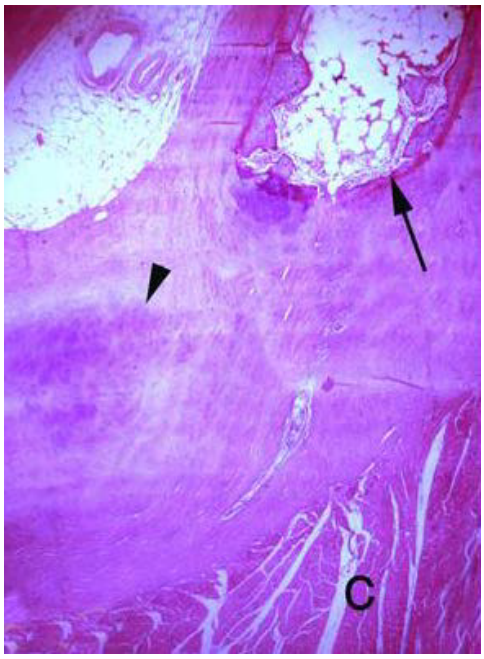

Figure 2: A photomicrograph of the Os cordis showing the spongy bones (arrow), the hyaline cartilage (arrow head), cardiac muscle (C). Stain: H& E Obj.x 2.5: Oc.x10.

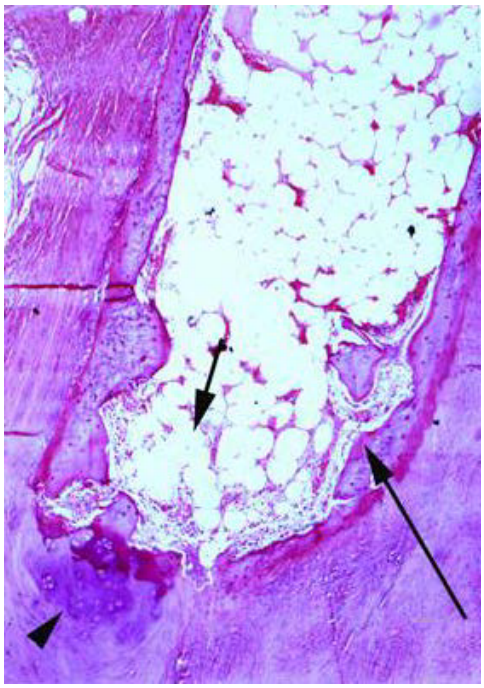

Figure 3: Higher magnification of Figure 1 showing the spongy bones (long arrow), the calcified hyaline cartilage (arrow head), bone marrow (short arrow). Stain: H& E Obj.x 5: Oc.x10.

Meanwhile, no fibrous body and no os cordis were found in the sperm whale heart [21].

Histologically, the camel heart skeleton is consisted of fibrous connective tissues that is mainly composed of coarse collagen fibers (Figure 1), with interspersed areas of fibrous cartilage (Figure 2), hyaline cartilage (Figures 3 and 4), calcified hyaline cartilage (Figures 2 and 5), initial ossification (Figures 3 and 5), and spongy bone (Figures 2 and 5). This result is very close and similar to the finding that described after Egerbacher et al. [7] in the Otter (Lutra lutra). Highly vascularized connective tissues with numerous adipocytes are present surrounding and supporting the cartilage and the bony structure (Figures 6-8).

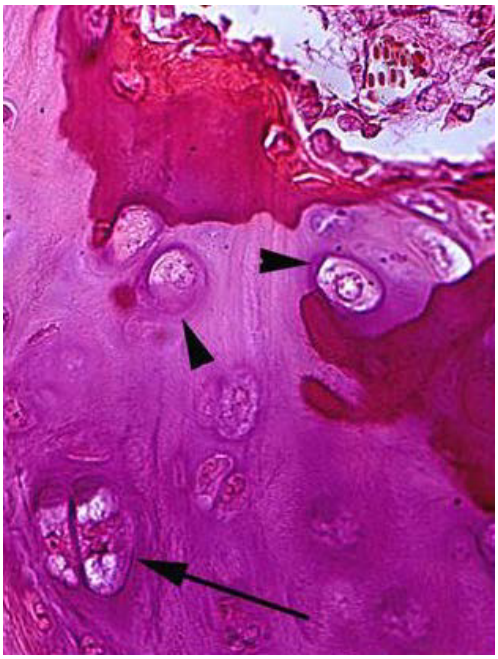

Figure 4: Higher magnification of Figure 4 showing the chondrocytes nest (arrow), single chondrocytes (arrow head). Stain: H& E Obj.x 40: Oc.x10.

Figure 5: Higher magnification of Figure 1 showing the adipose tissue (A), large blood vessels (arrow). Stain: H& E Obj.x 20: Oc.x10.

Well-developed, ossified hyaline cartilage is clearly defined as a cap for the spongy bone (Figures 2 and 9). The cartilago cordis; cartilage is consisting of numerous chondrocytes that present in single form, surrounded with lacunae and sometimes collected together forming cell nest within the basophilic matrix. Furthermore, calcification of the matrix material occurred in the central areas of the hyaline

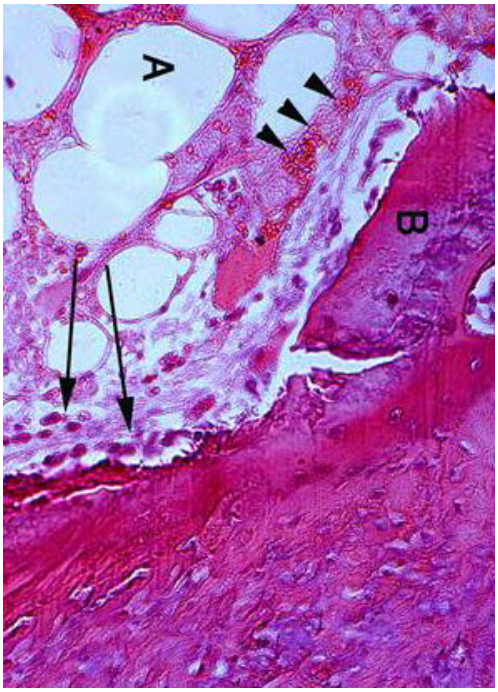

Figure 6: A photomicrograph of the bone marrow showing the adipose tissue (A), RBCs (arrow head), osteocytes (arrow) and bone (B). Stain: H& E Obj.x 40: Oc.x10.

Figure 8: Higher magnification of Figure 7 showing the chondrocytes nest (arrow), single chondrocytes (arrow head) with basophilic matrix. Stain: H& E Obj.x 40: Oc.x10.

Figure 7: A photomicrograph showing the calcification of the hyaline cartilage (arrow head), the hyaline cartilage with chondrocytes (arrow). Stain: H& E Obj.x 10: Oc.x10.

Figure 9: Higher magnification of Figure 7 showing the conversion of the hyaline cartilage to bone with presence of chondrocytes (arrow) Stain: H& E Obj.x 40: Oc.x10.

cartilage close to the bone. And also, the mineral deposits stained deep blue with the haematoxylin. Remarkably, chondrocytes within the areas of calcification presented as morphologically inconspicuous vital cells (Figures 3 and 5). Furthermore, somewhat small foci of the hyaline cartilage are not clearly defined; a perichondrial layer is missing with slightly-defined chondrocytes and lacunae (Figures 10 and 11). Moreover, hyaline cartilage is continuously transformed into surrounding fibrocartilage that again transformed into coarse connective tissue (Figure 4). The latter, makes a strongly attachment and fixation for the cardiac muscles with the os cordis and cartilago cordis (Figure 4). These investigations and indications are very close and similar to the finding that described after Egerbacher et al. [7] in the Otter (Lutra lutra) (Figures 12 and 13).

The developmental stages of bone formation showed conversion of some normal hyaline cartilage pieces with basophilic matrix to calcified cartilage with slightly red and eosinophilic matrix. The calcified cartilage is gradually converted to spongy bone with irregular bone lamellae. Moreover, the spongy bone showed having red & white bone marrow with numerous RBCs, adipocytes and osteocytes. The ossification is depending up on the increasing of ca ions precipitation (Figures 2,3 and 5). These investigations are in parallelism with Egerbacher et al. [7] in the Otter (Lutra lutra) who clarified that in addition to the bones, 1-3 pieces of cartilage and cartilage with initial ossification were frequently found. Furthermore, the bony structures have red and white bone marrow. Moreover, they claimed that the calcium deposits were found in the matrix of the intact cartilage with vital chondrocytes [24,25].

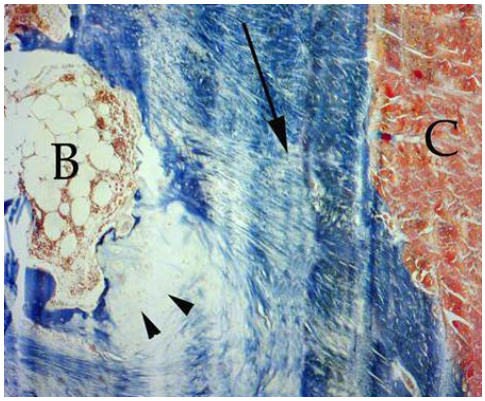

Figure 10: Showing the spongy bone (B), hyaline cartilage (arrow head), collagen fibers (arrow), and cardiac muscle (C). Stain: Azan Obj.x5: Oc.x10.

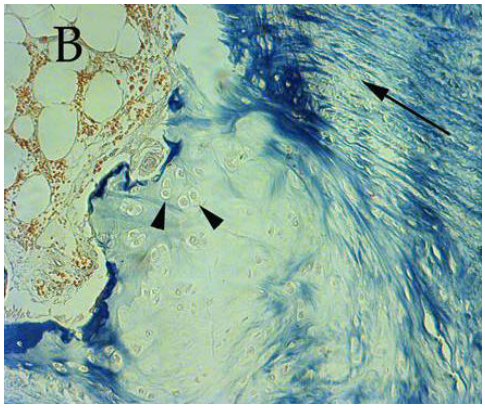

Figure 11: Higher magnification of Figure 10 showing the spongy bone (B), hyaline cartilage with chondrocytes nests (arrow head) and the collagen fibers (arrow). Stain: Azan Obj.x10: Oc.x10.

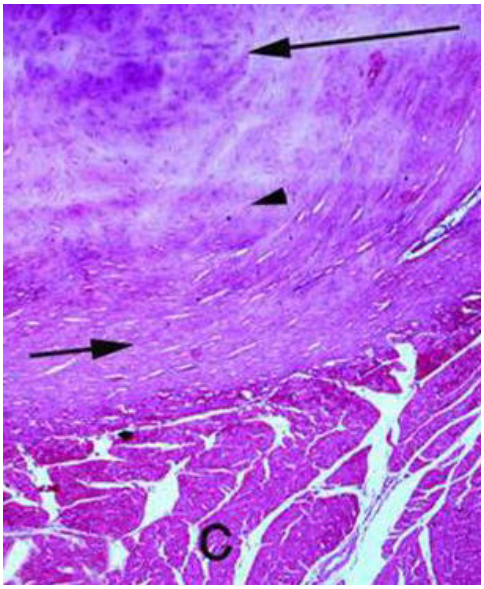

Figure 12: A photomicrograph showing the hyaline cartilage (long arrow), fibrous CT. (short arrow), cardiac muscle (C). Stain: H& E Obj.x5: Oc.x10.

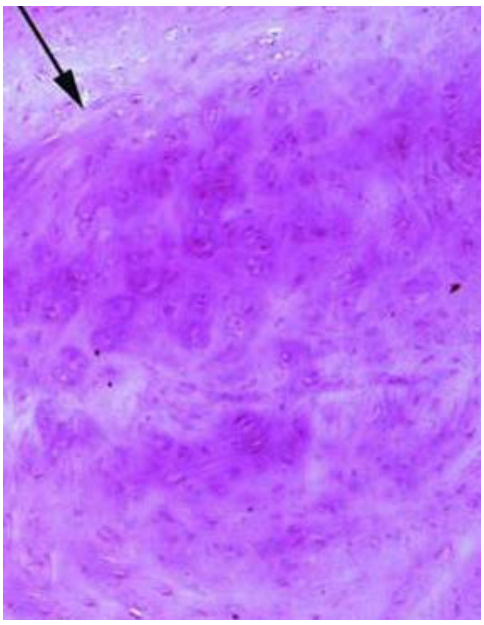

Figure 13: Higher magnification of Figure 12 showing the hyaline cartilage with basophilic matrix and chondrocytes (arrow). Stain: H& E Obj.x20: Oc.x10.

Hyaline cartilage is continuously transformed into surrounding fibrocartilage that again transformed into coarse connective tissue that supporting and connecting the cardiac muscle fibers with bones (Figures 1,3 and 4). Moreover, calcification of the matrix material occurred in the central areas of the hyaline cartilage close to the bone (Figures 2 and 5). This investigation indicating that the cartilage is considered an intermediary state during differentiation of bone from

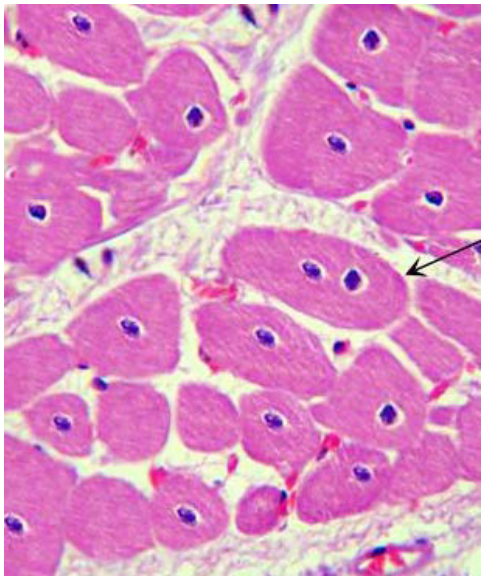

Figure 14: A photomicrograph showing the cardiac myocytes. Stain: H& E Obj. x40: Oc.x10.

the fibrous connective tissue. The initial ossification did not occur as direct, primary ossification of connective tissue but was regularly seen on pieces of cartilage, predominantly on edges or crest**.**

Moreover, the os cordis observed strongly attached to the surrounding cardiac muscles by coarse fibrous connective tissue that is mainly composed of collagen fibers (Figures 1 and 2).

Furthermore, the increasing amounts of calcified cartilage and the development of bony structures in the camel heart skeleton don't sex and size of the organ dependent but age dependent, which seems to be a sign of a high load of mechanical forces and high pressure in the atrioventricular plane and the aortic ring of the heart during systole. This investigation is in agreement with Dellmann and Eurell [3], Gartner and Hiatt [4] who stated that the nature of the heart connective tissue skeleton is species and age dependent. Further support comes from the findings in the pig heart, where the bony pieces were noted only in the animals older than three years [13].

The cardiac myocytes attaching the cartilage and the bony structure are appeared in the cross sections as an irregular polygonal cells of various sizes with a large, round, pale-staining, euchromatic, centrally placed, single nucleus and also sometimes, binucleated cells**.** The cardiac muscle sarcoplasm is an eosinophilic, full of contractile myofibrils (Figure 14). These findings are completely close to the findings of Ghonimi et al. [26] in the camel left atria and Ghonimi et al. [27] in the camel moderator bands.

Conclusions

We were concluded that the os cordis is the strongest part of the cardiac skeleton that stabilizing the heart during contraction and relaxation where at which the cardiac muscles are inserted. It is consisting of fibrous connective tissue, pieces of hyaline cartilage, calcified cartilage and large piece of spongy bone with red and white bone marrow. Somewhat the hyaline cartilage is not clearly defined; a perichondrial layer is missing with slightly-defined chondrocytes and lacunae. The hyaline cartilage is calcified and gradually converting to bones that support the cardiac muscles.

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