American Journal of Biomedicine and Pharmacy
https://biojournals.us/index.php/AJBP
ISSN: 2997-7177

Comparative Morphometric Analysis of Iraqi Sheep (Ovis Aries) and Goats (Capra Hircus) Papillary Muscles, Tendinous Chords, and Os Cardis: Cardiac Anatomy

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Received: 2024, 15, Jun
Accepted: 2025, 21, Jul
Published: 2025, 07, Aug

Annotation: Functionally relevant components of the atrioventricular valve complex include papillary muscles and chordae tendineae, which facilitate competent valve closure and unidirectional blood flow. Although comparative information on morphometric and anatomical differences in these structures is key, it is limited in domestic ruminants. For comparison of anatomical position, shape, number, and morphometric sizes of papillary muscles and chordae tendineae in sheep and goats' hearts, and evaluation of their functional implications. Methods: The hearts of eight healthy adult goats and eight healthy adult sheep were included in this research. Individual details of the chordae tendineae and papillary muscles (origin, insertion, length, number, arrangement etc.) were detected and measured through careful dissections. Statistical analysis and interpretation of the morphometric observations were made in the light of the established physiological functions of these structures. Similar observations were made in goats and sheep, with goat hearts having smaller, less prominent papillary muscles and thinner, less organized chordae tendineae when compared with sheep. Papillary muscles were found on the ventricles of both species, with species based differences in number and form. Interspecies differences in the length and diameter of the chordae tendineae with varying patterns of branching and points of insertion ($p < 0.05$). These morphologic differences suggest adaptations associated with optimal hemodynamics and species-derived cardiac requirements.

These structural differences appear to be consistent with functional specialization between the sheep and goats. These observations extend the current knowledge of ruminant cardiac anatomy and may be of value in ruminant veterinary cardiac diagnostics and interventions in the future.

Keywords: Heart, papillary, Chordae, valve, goats, sheep

Introduction

Anatomical structures of the heart, such as papillary muscles, chordae tendineae, and moderator bands, have an essential role in preserving normal cardiac valve function and mechanical synchrony between the heart chambers at all instants of the cardiac cycle. These structures as a whole structures form the subvalvular apparatus and they contribute significantly to the attachment of the atrioventricular valves and prevent them from prolapsing into the systole [1,2].

Originated of the pappillary muscles from the internal side of the ventricley and attach to the valve leaflets via the chordae tendineae, collagenous tendon-like cords. This anatomy helps the coordinated activity of the valves, ensuring the movement of blood is only unidirectional from the atria to the ventricles [3,4]. The moderator band, a unique myocardial structure in the right ventricle, apart from providing mechanical support, serves as a track for parts of the cardiac conduction system to facilitate coordinated ventricular contraction [5, 6].

Subvalvular apparatuses of these desire valves seem to have undergone considerable anatomical diversity among mammalian species, with various forms suited to species-specific hemodynamic demands [7,8]. For example, specific forms and orientation of the chordae tendineae and papillary muscles have also been reported in ruminants, e.g., sheep and goats and they have been interpreted as part of their functional adaptations to the heart in relation to their circulatory physiology [9,10]. These findings are in line with more general veterinary anatomical and physiologic data [11–13].

Although the anatomic descriptions are summarized in general veterinary anatomical texts [14–17], comprehensive regional variations and the exact dimensions of these structures in Iraqi goat and sheep are not available. Furthermore, little is known about the quantitative interrelationship of subvalvular structures, such as the number and size relationship of the chordae tendineae to the relevant papillary muscle [18–20].

The present work attempts to eliminate this gap by thoroughly considering the anatomical and morphometric features of the papillary muscles, chordae tendineae, and moderator bands in the hearts of the Iraqi sheep and goat. By using comparative gross structure and statistical correlation analyese, this work contributes to elucidation of species-related differences of cardiac anatomy and possible physiological significance. analyses, this investigation contributes to knowledge of species- specific cardiac anatomy and its implications in physiological functions.

Materials and Methods

The study was conducted on the hearts of sixteen apparently healthy mature animals, eight Iraqi sheep and eight Iraqi goats. Samples were collected at slaughtering time from Al-Diwaniyah municipal slaughterhouse, Al-Qadisiyah Governorate, Iraq. Prior to slaughter, all animals were evaluated by general examination of soundness by the veterinarian and no gross pathologic change, systemic disease was noted and deemed fit for the anatomical study.

Following the humane killing and excision of the heart, it was carefully dissected in situ. The interventricular and atrioventricular grooves were incised along the right and left ventricles to open them and expose the internal features without damaging the papillary muscles, chordae tendineae, and moderator bands.

Anatomical Structures in the Heart Both hearts were dissected The following structures in each heart were examined and noted: (1).

• Papillary muscles in the ventricles: their number, distribution and general shape.

• Origin, insertion, course, and distribution of the chordae from the papillary-muscles toward the atrioventricular valve leaflets.

• Existence, configuration and anatomical relations of the moderator bands in particular the right ventricle.

The morphology measurements were done by using a digital vernier caliper (precision ±0.01 mm). Parameters measured included:

• Dimensions of each muscle include (width, length, and thicknesses).

• Quantity and size of the chordae tendineae.

• Moderator-band (if present) length and width.

To exclude the inter-observer variability and to standardise me modifications on power and frequency, each of the parameters were measured three times in each specimen by a single observer for accuracy. The data obtained were compiled and analyzed using simple descriptive statistics (mean ± standard deviation) to define interspecies variability of anatomical structures [21].

No ethical approval was required as samples were taken from animals slaughtered for routine commercial meat production with local veterinary control, and under normal municipal inspection.

Statistical analysis data

The study included an aggregate of 16 fresh hearts (8 Iraqi sheep hearts as well as 8 Iraqi goat hearts). Morphometric measurements were performed and analysed using Microsoft Excel 2019. Comparison of the chordae tendineae and of the left and right papillary muscles was the main object of study. The number of chordae tendineae, and the lengths and width of the papillary muscles were some of the most important variables measured. In order to test differences in their morphologies means and standard errors were reported.

Results

Anatomical examinations of the heart in the two targeted animals (sheep and goat) revealed that the inner surface of the right ventricle projected into the ventricular cavity with three papillae, while there were only two in the left ventricle. Each papilla was named according to its location: septal, angular, and parietal. These papillae are connected by chordae to the tricuspid valves of the right atrioventricular valve, and the septal and parietal papillae control the mitral valve of the left atrioventricular valve.

In sheep, We observed that the right parietal papillary muscle is shifted to central third of the ventricles with a conical top; the right septal muscle is shifted to central third of the ventricles, with a three-way top; the right angular muscle is shifted toward the higher third of the ventricles, with an top shaped like the dome (Fig. 1) (Table. 1); the left parietal muscle corresponding to the higher third of the ventricle and the top is bifurcate; and the left septal muscle in the higher third of the ventricle and the top is trifurcate (Figure 2) (Table. 1).

In Goats, The right parietal papillary muscle originates in the central third of the ventricle and has a trifurcate top; the right septal muscle originates in the middle of the ventricle and has a trifurcate top; the right angular muscle is found in the higher third of the ventricle and has a conic top (Fig. 1) (Table. 2).; the left parietal muscle also relates to the higher third of the ventricle with a conical top; and the left septal muscle is related to the higher third of the ventricle with a four-branch top (Fig. 2) (Table. 2).

In the sheep, the right parietal papillary muscle is 2.4 ± 0.73 cm wide, 3.3 ± 0.7 cm long, and have an average area of 8.3 ± 0.94 cm² and encompasses approximately 6.33 ± 0.47 chordae tendineae. The septal muscle is 2.0 ± 0.1 cm wide, 4.6 ± 0.07 cm long, covers 11.7 ± 0.63 cm² in area, attached to 6 ± 0.67 chordae tendineae right septal muscle. The right angular muscle measures 1.8 ± 0.2 cm across, 5.9 ± 0.2 cm in length, occupies an area of 13.2 ± 0.04 cm² with 5.67 ± 0.33 chordae tendineae. On the left it is the left parietal muscle with 1.5 ± 0.21 cm wide, 6 ± 0.1 cm long, 9.8 ± 0.15 cm² of area with exactly 6 chordae tendineae. The left septal muscle is 1.34 ± 0.01 cm wide, 5.7 ± 0.04 cm long, covers 7.3 ± 0.21 cm², and it inserts 4.33 ± 0.33 chordae tendineae (Table. 3).

For goat, the right parietal papillary muscle is 1.8 ± 0.2 cm wide horizontally, 5.2 ± 0.31 cm long vertically, 9.9 ± 1.13 cm², and 5.67 ± 0.9 chordae tendineae inserting. The right septal muscle measures 3.4 ± 0.96 cm in width, 5.1 ± 1 cm in length, 16.2 ± 1.5 cm² in area, and is attached to 5.33 ± 0.22 chordae tendineae. The right angular muscle has a width of 1.7 ± 0.17 cm, length of 6.4 ± 0.4 cm, area of 11.6 ± 2.22 cm², and 5.67 ± 0.24 chordae tendineae. On the left, the left parietal leaflet muscle is 1.6 ± 0.22 cm wide, 6.6 ± 0.4 cm in length, and 9.7 ± 1.11 cm² in area with 4 chordae tendineae precisely. The left septal muscle is 1.5 ± 0.58 cm wide, 6.0 ± 0.11 cm long, 10.4 ± 1.41 cm² in area, and also connected to 4 chordae tendineae (Table. 3).

The os cordis, present in the heart of ruminants, also demonstrates size discrepancy between animals. In goats, it measures 1.4 ± 0.09 cm long, 0.2 ± 0.00 cm thick, and 0.4 ± 0.03 cm wide. In sheep, on the other hand, the os cordis is slightly longer (1.7 ± 0.06 cm), 0.1 ± 0.03 cm in profile, and 0.5- ± 0.06 cm wide. However, even though the os cordis was thinner and exhibited much thickness and width variation, it was not present in the thickness measure versus the body composition variables (Table. 4).

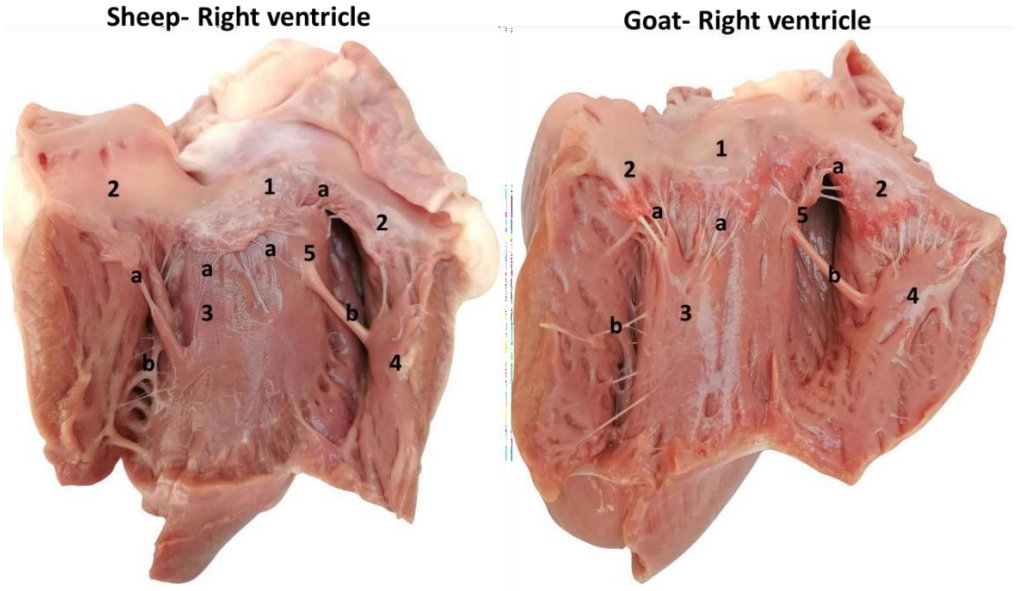

Figure (1): The right ventricle of sheep and goat appears: the septal (1) and parietal (2) cusps of the tricuspid valve. septal (3), parietal (4), and angular (5) papillae. The chordae tendenae (a). The moderate bands (b).

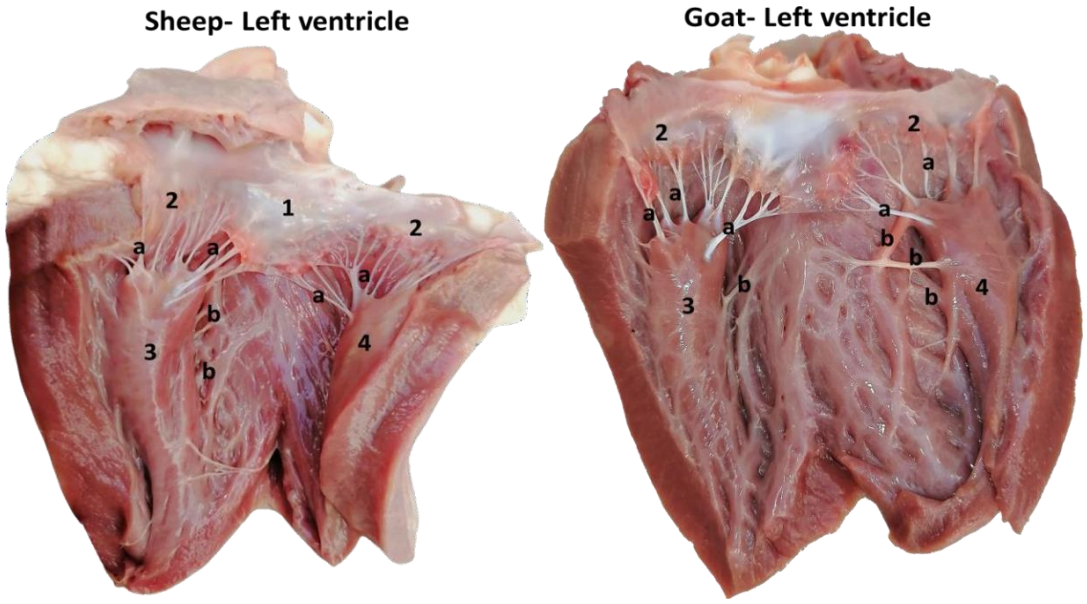

Figure (2): The left ventricle of sheep and goat appears: the septal (1) and parietal (2) cusps of the mitral valve. The Septal (3) and parietal (4) papillae. The chordae tendineae (a). The moderate bands (b).

Table (1) The papillary muscles in sheep.

Papillary muscles	Top appearance	Location
Right Parietal	Conical	The central third of ventricle
Right Septal	Trifurcate	Central third of ventricle
Right Angular	Dom-shaped	The higher third of ventricle
Left Parietal	Bifurcate	The higher third of ventricle
Left Septal	Trifurcate	The higher third of ventricle

Table (2) :The papillary muscles in goat.

Papillary muscles of Goat	Shape of Apex	Location of origin
Parietal R.	Trifurcate	Middle third of ventricle
R. Septal	Trifurcate	Middle of ventricle
R. Angular	Conical	Higher third of ventricle
L. Parietal	Conical	Higher third of ventricle
L. Septal	Four-furcate	Higher third of ventricle

Table (3) The mean values for the width, length, area, and number of papillary muscles. The abbreviations: No: number, R: right, L: Left, P: Parietal, S: Septal, A: Angular, G: Goat, SH: Sheep

Papillary Muscles	Horizontal Width (CM)	Vertical Length(CM)	Area (CM^2)	No. of Chordae Tendineae
R. P.G.	1.8 ± 0.2	5.2 ± 0.31	9.9 ± 1.13	5.67 ± 0.9
R. S.G.	3.4 ±0.96	5.1 ± 1	16.2 ± 1.5	5.33± 0.22
R. A.G.	1.7 ± 0.17	6.4 ± 0.4	11.6 ± 2.22	5.67± 0.24
L. P.G.	1.6 ± 0.22	6.6 ± 0.4	9.7 ± 1.11	4 ± 0.00
L. S.G.	1.5 ± 0.58	6.0 ± 0.11	10.4 ± 1.41	4 ± 0.00
R. P.SH.	2.4 ± 0.73	3.3 ± 0.7	8.3 ± 0.94	6.33± 0.47

R. S.SH.	2.0 ± 0.1	4.6 ± 0.07	11.7 ± 0.63	6 ± 0.67
R. A.SH.	1.8 ± 0.2	5.9 ± 0.2	13.2 ± 0.04	5.67± 0.33
L. P.SH.	1.5 ± 0.21	6 ± 0.1	9.8 ± 0.15	6 ± 0.0
L. S.SH.	1.34 ± 0 .01	5.7 ± 0.04	7.3 ± 0.21	4.33± 0.33

Table (4): The average of length, thickness, and breadth of the Os Cardis in Sheep and Goat

Os Cardis	Length	Thickness	Breadth
Goat	1.4 ±0.09	0.2 ± 0.00	0.4 ± 0.03
Sheep	1.7± 0.06	0.1 ± 0.03	0.5 ± 0.06

Discussion

The present study provides a detailed comparative anatomical and morphometric analysis of the papillary muscles, chordae tendinee and os cordis of the sheep and goat hearts. The findings are illustrated with respect to location, structural orientation, morphometric characteristics and species manifestations on an organ- and species-specific degree of adaptation of the cardiovascular system.

Consistent with previous studies [9,7] in mammalian heart, our morphometric analysis demonstrated that the left ventricles of both goat and sheep had two major papillary muscles—septal and parietal, although the single set of data represented each species. These muscles protruded into the ventricular cavity and attached to the ventricular inner wall. The papillary muscles in sheep were longer, thicker, and more vascular than those in porcine, which corroborates earlier findings published elsewhere [1], and perhaps due to their larger heart size and greater circulatory need.

Histologically, while it was beyond the scope of our protocol to do detailed histochemical staining of tissues, our macroscopic observations supported the previous studies by Fawcett & McNutt [23] with regard to the interstitial course of the myocardial fibres in the papillary muscles, which is involved in maintain tension on the atrioventricular valves during systole [16,24].

In both types, the crests of the papillary muscles represent the origin of the chordae tendineae that attach to the cusps of the AV Valve. Our results confirmed the three functional chordae: marginal, basal, and secondary, agreeing with previous anatomical typologies [3,25]. Chordae tendineae were more and thickened than those of the sheep, in relation with the need to bear the higher ventricular pressure [4,26]. The goats' chordae were more delicate and less budding, possibly reflecting their smaller heart and lower systemic load.

Moreover, in sheep this difference was more pronounced than that found in pigs; as breed and age-related differences in structure are consistently characterised in other studies [10,27].

Moderator band (trabecula septomarginalis) was observed continuously in both species from the septal wall to the septal papillary muscle. Its presence also serves not only to help ventricular conduction[6,28] but as a biomechanical anchor for force distribution[29]. These traits highlight the mechanical–electrical coupling of the subvalvular apparatus and contribute to the validity of sheep and goats as comparative animal models for human cardiovascular studies.

Another new aspect of the present work is analysis of the morphometry of the os cordis, a sesamoid-like bone within the fibrous part of the cardiac skeleton of some ruminants. In goats, the os cordis was 1.4 ± 0.09 cm and long, 0.2 ± 0.00 cm thick, and 0.4 ± 0.03 cm wide. The os cordis was larger in sheep, measuring 1.7 ± 0.06 cm in length and 0.5 ± 0.06 cm in width, although it was thinner overall (0.1 ± 0.03 cm). Whereas goats showed a constant cross-sectional area, sheep exhibited more inter-individual variation in thickness and a larger inter-individual variation of the width.

These differences in os cordis size may reflect the physiological and mechanical loads experienced by the cardiac base in these species. The os cordis offers structural stiffening and electro-mechanical conduction support in the area of the atrioventricular junction with the possibility that

its variation might be influenced by age, species, workload or genetic effects [30,31]. The presence and amount of the os cordis in sheep, with a higher circulatory load, may indicate mineralization driven adaptation of the support of the heart skeleton.

The results of these measurements in particular of papillary muscle mass, chordal branching and os cordis size, highlight species-specific adaptation to circulatory load. Higher architectural and vascular structures of subvalvular apparatuses in sheep are considered to be beneficial for high pressure cardiac physiology and mitral valve or tricuspid valve surgery simulations. Their anatomic similarity to the human heart has been often reported [32,33], supporting the translational value of ovine models in cardiovascular biomechanic studies, prosthetic testing and valvular repair training [34,35].

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