The comparative investigation of left ventricle papillary muscle arteries in different species

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ABSTRACT

Objectives: To determine whether similar histologic findings exist in left ventricle papillary muscle arteries in different species and to elicit whether those animal hearts may be used as models for human heart in experimental studies related to papillary muscles.

Methods: We examined 360 samples taken from the tip, mid-portion and base of papillary muscles in 60 normal adult hearts (15 each from human, dog, sheep, goat). The samples were obtained from Dicle University and Kahramanmaras Sutcu Imam University, Turkey and the study was conducted in June-September 2004. Tissues were processed by routine histologic methods, stained with hematoxylin-eosin and van giesson, and later evaluated under a light microscope.

Results: While the values of human and dog heart resembled each other by means of left ventricle papillary muscle arteries, the hearts of sheep and goat were also found to be similar. The number of thin walled arteries increased from the tip (18%) to the base (48%), intermediate walled arteries decreased from the tip (56%) to the base (14%), thick walled arteries decreased from the tip (62%) to the mid-portion (38%). The differences among human and animals were not statistically significant in any group. We found that the thickness values of papillary muscle arterial walls at the tip, mid-portion and base varied from 4.86 μm to 107.7 μm in all species. The difference among values of human and animals was not significant statistically ($p>0.05$).

Conclusion: The values for arterial walls of tip, mid-portion and base of papillary muscles were similar between human and dog, sheep and goat. These morphologic findings in human and animal hearts of different species prove that anatomists, cardiologists, experimental investigators, pathologists and physiologists may benefit from the hearts of those animals as a good model to imitate the human heart in experiments concerning papillary muscles.

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The aim of our study was to determine whether similar histologic findings exist in the left ventricle papillary muscle arteries in different species and to elicit whether the animal hearts may be used as a model for human heart in experimental studies related to papillary muscles. Understanding of cardiac anatomy, truly a prerequisite for successful cardiac surgery, will be facilitated in future if words are used in their generally accepted sense, and if artificial conventions are avoided.[1] On the internal or parietal surface of the left ventricle in man and in mammals are 2 papillary muscles, which are almost identical and well developed; these muscles are known as the musculus papillaris anterior and the musculus papillaris posterior.[2] As a rule, the papillary muscles are supplied by more than one segmental

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artery, therefore, anatomical variations may play an important role in functional alterations produced by ischemic lesions of the myocardium.[3] Left ventricle papillary muscle (LVPM) arteries have been classified according to semiquantitative estimate of the number of smooth muscle cell (SMC) fibers found in the tunica media (TM) into one of 3 groups: Group 1 normal amount (1-3 layers), normal lumen (round or oval lumen with an intact tunica intima). Group 2 samples mild to moderately increased amount of SMCs, with narrowness, eccentric displacement, and uneven lumen shape. Group 3 samples with abundant SMCs duplicated the arterial size, contrary to the other 2 groups. Their shape was round and their extremely narrow, centrally located lumen had a round or oval shape.[4,5] Papillary muscles of the left ventricle are prone to ischemic damage but seldom rupture, perhaps because they are protected by transendocardial diffusion and thebesian sinusoids as well as by arteries. The authors in an article hypothesized that the apex of human left ventricle was adapted for sinusoidal flow to papillary muscles.[6] All aspects of mitral valve complex including the annulus, leaflets, commissures, chordal structures and papillary muscles are so important to attain integrity and proper geometric modelling of the left ventricle for systolic pump function. Deficiency or degeneration of one or more of these structures may result in dysfunction of the valvular apparatus leading to mitral valve prolapse during systole.[7-15] Primary prolapse results from congenital structural defects of intracardiac formations (papillary muscles, trabecules, chordae) of the left ventricle, as well as associated microcirculatory disorders.[16] These detailed anatomic studies concerning the anterior and posterior papillary muscles in the left ventricle will provide anatomists and cardiac surgeons with valuable knowledge.[12-14] Therefore, we planned to compare the morphology of papillary muscle arteries of left ventricle in different species.

Methods. We examined 45 animal hearts from dogs (15), sheep (15), and goats (15), and 15 cadaver human hearts. Human cadavers were of adult Caucasian people. Sheep and goat hearts were obtained from slaughter house in Diyarbakir and Kahramanmaras, dog and human hearts from the Departments of Anatomy of Veterinary and Medical Faculties of Dicle University and Kahramanmaras Sutcu Imam University and the study was conducted in June-September 2004. All hearts were fixed with 10% formalin. Left margin of each heart was opened to examine the inside of left ventricle. The tissue samples (2-3 mm in length) were taken from the tip (2-6 mm from the extremity), mid-portions and base of the left anterior papillary muscle, as well as the posterior papillary muscle, with perpendicular cuts through the long axis. Therefore, we examined histologically a total of 360 samples taken from 60 hearts. Tissues were promptly fixed in 10% neutral formol for approximately 2-3 weeks and then, after processing, were embedded in paraffin. Sections (4-6 μm) were obtained and stained with hematoxylin-eosin and van giesson. We classified the papillary muscle arteries into 3 groups according to the estimate of number of smooth muscle cells in tunica media as reported by Nerantzis et al.[4,5] Then we measured the thickness of papillary muscle arteries by the use of ocular micrometer under a light microscope.

Statistical analyses were performed by one-way anova and post hoc test in SPSS 10.0 computer software (SPSS Inc., Chicago, IL).

Results. ***Macroscopical examination.*** The anterior and posterior papillary muscles were present in 100% of cases of both human and animal hearts. We found that the shapes of papillary muscles were quite similar in animal hearts, while the variations of shapes of papillary muscles were more established in human hearts. The papillary muscles' support had one belly in many hearts (extending freely like a finger to the ventricular cavity), and 2 or 3 bellies with a wider and common base in some hearts of human. When there were 2 or 3 bellies, they presented configurations such as V, Y or H. On the other hand, papillary muscles were generally composed of one belly in hearts of all animals. The single papillary muscles were conical or mammillated.

Microscopical examination. We classified the arteries of papillary muscles into 3 groups according to the number of smooth muscle cells in tunica media (**Table 1, Figures 1-6**). Thin walled arteries increased from the tip (18%) to the base (48%), intermediate walled arteries decreased from the tip (56%) to the base (14%), and thick walled arteries decreased from the tip (62%) to the mid-portions (38%). The differences between human and animals are not statistically significant in all groups (p>0.05) (**Table 1**).

Thin walled. The number of SMC in the TM was normal (1-3 layers). The lumen was also normal (the internal elastic lamina was developed and external elastic lamina was thin). The arteries of this group were concentrated at the base of papillary muscles (48%) (**Table 1, Figure 1**).

Intermediate walled. There was a mild to moderate increase in SMC in the TM causing an inversely related degree of narrowing and eccentric

Table 1 - The number of arteries of each type in 3 portion of the papillary muscles.

Species/ papillary muscles	Tip portion			Mid portion			Basal portion		
	Thin	Inter mediate	Thick	Thin	Inter mediate	Thick	Thin	Inter mediate	Thick
Human									
Anterior	4	11	3	6	6	1	11	3	-
Posterior	4	10	3	7	6	2	10	3	-
Dog									
Anterior	4	11	3	7	5	2	11	2	-
Posterior	4	11	3	8	5	2	10	2	-
Sheep									
Anterior	3	11	3	7	6	2	11	2	-
Posterior	3	12	3	7	6	1	10	3	-
Goat									
Anterior	5	10	2	8	6	2	9	3	-
Posterior	4	11	3	7	7	2	8	3	-
Total (%)	**18**	**56**	**62**	**34**	**30**	**38**	**48**	**14**	

dislocation of the lumen. The internal elastic lamina was well developed in most samples. The external elastic lamina was also thin. The arteries in this group were concentrated at the tip of the papillary muscles (56%) (**Table 1, Figure 2**).

Thick walled. There were abundant number of SMC in the TM of the arteries of papillary muscles. The internal elastic lamina was well developed in most samples. The external elastic lamina was thin or incomplete. Thick walled arteries were concentrated at the tip of the papillary muscles (62%) (**Table 1, Figure 3**). We did not find any thick walled arteries in the samples taken from the base of the papillary muscles (**Table 1**). We found that the thickness values of the arteries at the tip, mid-portions and base of papillary muscles varied from 4.86 μm to 107,7 μm in all species. The difference between values of human and animals was not statistically significant (p>0,05). Those values of tip, mid-portion and base of papillary muscles were similar between human and dog, and between sheep and goat (**Table 2**).

Discussion. Some studies have been conducted to date in the scientific world to determine whether similar histologic structure exists in left ventricle papillary muscle (LVPM) arteries, since these muscles are larger, attached to the left ventricle with a wider base, sustain a heavier workload and are exposed to an increased left ventricular intracavity pressure and higher oxygen content of arterial blood compared with the right ventricle papillary muscle arteries.[4,5] In a previous study, 2 basic types of arterial vessels were distinguished in the myocardium. a) Compacta or Ventricular Wall Type. Intramyocardial microarteries with ring musculature of the media. b) Papillary Muscle Type. Arteries with longitudinal musculature arranged as bundles in the broad media.[17] The papillary muscles play an important role in the preservation of the competence of atrioventricular valves. This has become more evident since the recent description of the clinical syndrome of papillary muscle dysfunction. The anatomists and cardiologists have undervalued the morphologic characteristics of the papillary muscles except to note that the papillary muscles are specialized forms of trabeculae carneae and that they are variable in number, size and shape. Similarly, vascular anatomy and histology of this region of the ventricles has received little attention until recently.[7,12,13] Therefore, we planned to make a detailed histological investigation of papillary muscle arteries in different species. But we discussed our results only with those of Nerantzis et al[4] since the histological studies related to papillary muscle arteries were rather limited. In our study, the arteries of papillary muscles were classified similar to Nerantzis et al, however they were named as thin walled (for group 1), intermediate walled (for group 2) and thick walled (for group 3) according to the estimated number of smooth muscle cells in tunica media. Grouping the arteries in such a way will be helpful to understand what kind of relationship there is between the structure and the function of papillary muscles. Thin walled arteries increased from the tip (18%) to the base (48%). However, intermediate walled arteries decreased from the tip (56%) to the base (14%), while thick walled arteries decreased from the tip (62%) to the mid-portion (38%). It

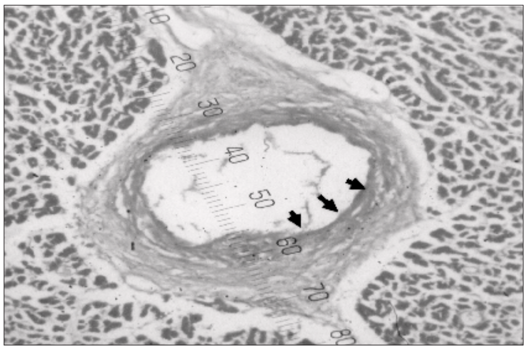

Figure 1 - Transversal section of a thin walled artery in the papillary muscle of human heart. Internal lamina, muscular layer in tunica media and external lamina are seen (Hematoxylin and Eosin, X 100). Arrowheads show tunica intima.

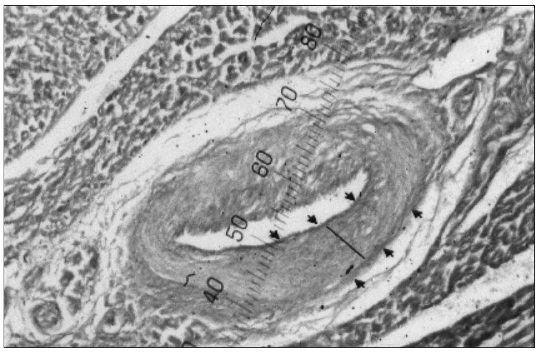

Figure 2 - Transversal section of an intermediate walled artery in the papillary muscle of dog heart. Internal lamina, thicker muscular layer in tunica media and external lamina are seen (Hematoxylin and Eosin, X 100). Arrowheads show tunica intima and externa. Black line shows tunica media.

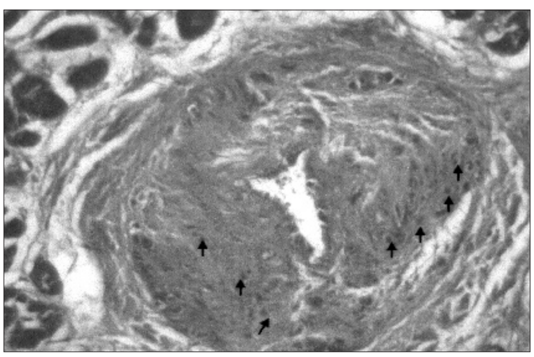

Figure 3 - Transversal section of a thick walled artery in the papillary muscle of human heart. Internal lamina, thicker muscular layer and external lamina are seen. Muscular layer is much thicker and the lumen is narrowed (Hematoxylin and Eosin, X 100). Arrows show the smooth muscle cells in tunica media.

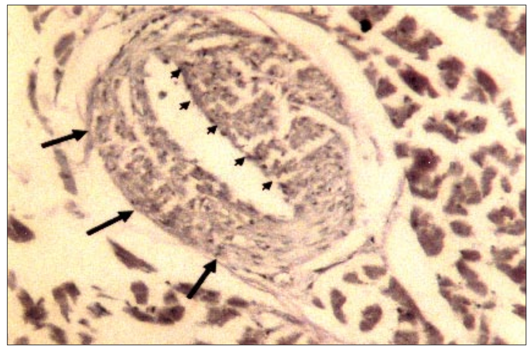

Figure 4 - Transversal section of papillary muscle artery of sheep heart (Van Giesson, X 100). Thin arrowheads show tunica intima and thick arrowheads show tunica externa.

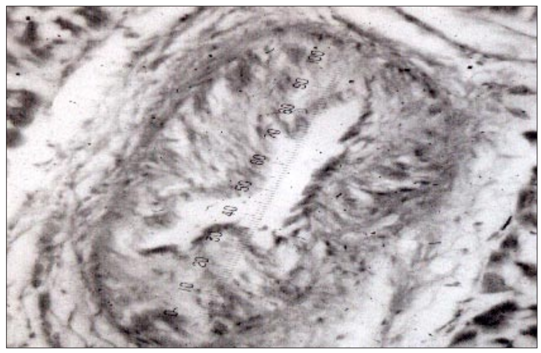

Figure 5 - Transversal section of papillary muscle artery of goat heart (Hematoxylin and Eosin, X 100).

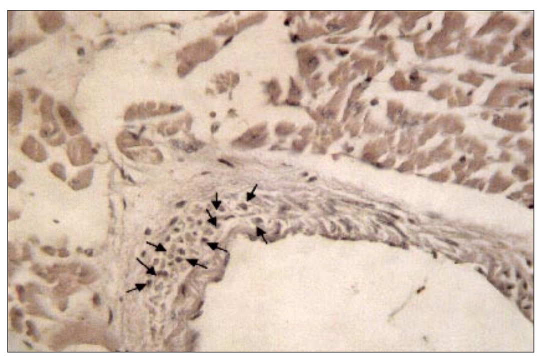

Figure 6 - Appearance of smooth muscle cells in transversal section of papillary muscle artery of human heart (Van Giesson, X 400). Arrows show the nuclei of smooth muscle cells in tunica media.

should be noted that thick walled arteries were found only at the tip and mid-portion of papillary muscles. The differences among human and animals were not statistically significant in all groups (**Table 1, Figure 1-6**). Nerantzis et al[5] reported that they estimated the number of SMC in the TM in 666 samples from the tip, mid-portion and base of the left ventricle papillary muscles separately. The prevalence of samples with group I arteries increased from the tip of the left papillary muscle (21%) to the base (47%). In contrast, in samples with group II arteries, the ratio decreased from the tip (44%) to the base (22%). Moreover, they pointed out that the samples with group III arteries were found only at the tip and mid-portion of left ventricle papillary muscles (63% and 37%, respectively). Our findings resemble the results reported by Nerantzis et al. We found that thin walled arteries had 1-3 layers of SMC in the TM and normal lumen. The internal elastic lamina was well developed and external elastic lamina was thin. Thin walled arteries were concentrated at the base of the papillary muscles (48%) (**Table 1, Figure 1**). The findings of Nerantzis et al related to Group I arteries were very similar to our findings. They only described the external elastic lamina as thin and incomplete, and gave the ratio of these arteries at the base as 47%. We also observed that intermediate walled arteries had a mild to moderate increase of SMC in the TM and a middle degree narrowing of the lumen. The internal elastic lamina was well developed in most samples. The external elastic lamina was thin. The arteries in this group were concentrated at the tip of the papillary muscles (56%) (**Table 1, Figure 2**). Nerantzis et al,[4,5] reported that there was a mild to moderate increase in SMC in the TM causing an inversely related degree of narrowing and eccentric dislocation of lumen, but without any increment in the external diameter of the arteries. The internal elastic lamina was well developed in half of the samples, and split and interrupted in the remainder. The external elastic lamina was thin, incomplete and almost absent in most samples. The arteries in this group were concentrated at the tip of the papillary muscles (44%). Our findings were harmonious related to Group II with those of Nerantzis et al. We found that thick walled arteries had abundant number of SMC in the TM. The internal elastic lamina was well developed in most samples. The external elastic lamina was thin or incomplete. The thick walled arteries were concentrated at the tip of the papillary muscles (62%) in all species and in human (67%). We did not find any thick walled arteries in the samples taken from the base of the papillary muscles in all species examined (**Table 1, Figure 3**). Our established data were parallel to those of Nerantzis et al, since they reported similar findings and their ratio for group III arteries at the tip of the papillary muscles was 63%. Nerantzis et al,[5] reported that the arteries in Group III were perfectly round, with a centrally located round or oval and narrow, almost occluded lumen (resembling a large rubber tractor wheel) serving as a hallmark for easy recognition. We observed in our specimens that the shape of thick walled arteries were similar to that reported by Nerantzis et al (**Figure 3**). Abundant amount of smooth muscle cells in the tunica media of LVPM arteries were found in 11% of samples in all species and in 10 % of samples in human. Nerantzis et al, reported that they observed Group III arteries in 9% of samples from LVPM, in contrast with the findings of a previous study, where they reported similar findings in 13% of samples

Table 2 - The wall thickness values of the arteries of papillary muscles in all species.

Species/ papillary muscles	Tip Portion Mean ± SD μm (minimum-maximum)	Mid Portion Mean ± SD μm (minimum-maximum)	Basal Portion Mean ± SD μm (minimum-maximum)
Human			
Anterior	32.56 ± 22.07 (7.29 - 97.2)	30.82 ± 17.7 (7.29 – 99.7)	26.38 ± 23.44 (4.86 - 97.2)
Posterior	34.79 ± 24.15 (7.29 – 106.37)	34.37 ± 24.09 (12.15 – 105.5)	27.55 ± 17.83 (7.29 – 96.7)
Dog			
Anterior	31.47 ± 23.98 (12.15 - 104.06)	30.40 ± 22.5 (4.86 – 105.5)	29 ± 21.3 (4.86 – 96.7)
Posterior	34.85 ± 29.88 (7.29 – 106.6)	33.4 ± 21.34 (7.29 – 107.71)	28.6 ± 21.8 (6.86 – 102.7)
Sheep			
Anterior	26.41 ± 18.03 (7.29 – 96.7)	27.23 ±14.06 (7.29 – 91.68)	23.51 ± 15.58 (4.86 – 97.69)
Posterior	29.12 ± 23.83 (4.86 – 103.5)	24.87 ± 11.33 (7.29 – 68.6)	21.58 ± 12.24 (7.29 – 69.88)
Goat			
Anterior	28.10 ± 13.36 (4.86 – 78.88)	25.06 ± 16.99 (4.86 – 87.36)	21.05 ± 14.89 (4.86 – 79.44)
Posterior	25.84 ± 10.62 (4.86 - 48.35)	23.51 ± 17.38 (4.86 -101.05)	23.32 ± 12.09 (4.86 – 87.03)

from the right ventricle papillary muscles. They commented that this difference could be attributed to the fact that the left papillary muscles were larger and attached to the ventricular wall with a wider base, thus having greater blood perfusion through the myocardium. Moreover, left papillary muscles are exposed to a higher oxygen content in arterial blood.[4,5] The results of our and Nerantzis et al's studies have supported each other related to Group III (thick walled) arteries for LVPM. We found that the thickness values of tip, mid-portion and base of papillary muscle arteries varied from 4.86 μm to 107.7 μm in all species. Mean values of the wall thickness of papillary muscle arteries decreased from the tip (34.85 ± 29.88 μm) to the base (21.05 ± 14.89 μm). The thickness values of tip were more than other portion values, because the number of thick walled arteries were more at the tip. The difference between values of human and animals was not significant statistically (p>0.05). The values for arteries at the tip, mid-portion and base of papillary muscles were similar between human and dog, and between sheep and goat (**Table 2**). Unfortunately, we could not find any histologic report related to papillary muscle arteries of animals (dog, sheep, goat) in the literature. But we realized that the values for LVPM arteries were resembling each other in human and dog hearts. On the other hand, the values related to LVPM arteries of sheep and goat were found to be similar as well. From this point of view, we think that dog, sheep and goat hearts can be used instead of human hearts in experimental studies related to papillary muscles.Undoubtedly, the number of arteries supplying papillary muscles varied from heart to heart depending on the species and individual variations. In a study by Ranganathan and Burch[7] the arteries of posterior papillary muscle in the left ventricle were found to take their origin mainly from circumflex artery and/or posterior interventricular artery. Likewise, anterior papillary muscle in the left ventricle took its arteries from anterior interventricular artery and/or diagonal left ventricular arteries or marginal branch of circumflex artery. The structure of vessels furthermore, exhibits changes according to the shape of papillary muscles. Thus, in a fingerlike papillary muscle there is a central artery giving many branches along its course in the papillary muscle itself. On the other hand, long penetrating intramyocardial vessels show a segmental distribution in a tethered papillary muscle. These vessels become enlarged after they enter the papillary muscle. Hence, our findings with thin walled arteries with a wider lumen located mainly at the base of the papillary muscles were concordant with the literature.[17] The arteries change their structure within the papillary muscle so as to adapt its functional burden. This ought to be an adaptation mechanism of the tissues or organs suitable to their functional goals. Since the pressure within the papillary muscle itself or in the ventricular cavity is very high during ventricular contraction, perfusion of the papillary muscles will be spared unless the walls of the arteries resist this pressure. Even though the lumen of the arteries is wide and the wall is thin at the base of the papillary muscles, the lumen becomes narrower and the wall becomes thicker as the artery courses towards the tip of the papillary muscle. Therefore, we think that the thick walls of the arteries located mainly at the tip of the left ventricle papillary muscles are strong enough to resist the pressure around them and are important to sustain the perfusion of the muscle cells. This is in turn very significant in the proper functioning of the papillary muscles clinically. We know that the mitral valve apparatus is a complex structure composed of an annulus, mitral leaflets, chordae tendinea, papillary muscles and left ventricular, atrial and aortic walls. If the blood supply to any of these structures, specifically to papillary muscles, is impaired, the whole valvular apparatus becomes affected. Hence, prolapse of the mitral valves may occur. These anatomic findings concerning with the features of arterial network of the anterior and posterior papillary muscles in the left ventricle combined with our previous description of the structures in the left ventricle, will provide a current insight to anatomists and cardiac surgeons on this subject. We believe that the knowledge about LVPM of animal hearts of dog, sheep and goat is very important, since it is necessary to know to what extent the morphological structure of the hearts of these animals resembles to that of human heart before experimental cardiac surgery. Moreover, we as well think that a more precise data collection and development of a model will further influence our understanding of the functional anatomy of subvalvular apparatus, and concept of reconstructive subvalvular surgery.

In conclusion, the values for arterial walls of tip, mid-portion and base of papillary muscles were similar between human and dog; sheep and goat. These detailed morphologic findings in human and animal hearts of different species prove that anatomists, cardiologists, experimental investigators, pathologists and physiologists may benefit from the hearts of those animals as a good model to imitate the human heart in experiments concerning papillary muscles.

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