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The Cardiac Septomarginal Trabecula In Man And Some Mammals

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ABSTRACT

The present work was designed to describe, in detail, the anatomy, morphometry and minute structure of the septomarginal trabecula of the right ventricle in man and some animals like camel, sheep and monkey. The results of this study would help to highlight the function(s) of such a band in these species. Furthermore, the full description of this trabecula in such animals might hopefully be of some value not only for academic comparative researches but also for the expectancy of utilization of any of them, in the future, in human cardiac reconstructive surgeries.

Forty adult hearts, of both sexes, (10 for each species) were used in this investigation for the comparative morphological, morphometric and light microscopic study of the septomarginal trabecula (moderator band) in man, Arabian camel, sheep and monkey. This work was carried out in the Anatomy and Histology Laboratories, College of Medicine, KFU, Dammam, KSA. The trabecula was grossly examined and morphometrically assessed. Histological sections of the trabecula were differently stained and examined by the light microscope.

The trabecula was observed to extend from the interventricular septum to the base of the anterior papillary muscle in man (or the muscle papillaris magnus in animals). In each of the four species investigated, the trabecula carried the specialized myocytes of the conducting right bundle branch that appeared as a longitudinal fibrocellular tract amongst ordinary myocardial fibres. The cells of this tract were faintly stained, foamy, arranged edge to edge in clusters, displaying a mosaic-like appearance, and increasing in size as traced distally. The minute structure of the trabecula was observed to be the most developed in sheep and the least in monkey. A tortuous small-sized artery was detected within the trabecula. No morphological or structural sex-differences of the trabecula existed in any of the species investigated. Some significant morphometric species-differences were detected.

KEYWORDS: Septomarginal trabecula (moderator band), anatomy, histology, morphometry, human, camel, sheep, monkey.

Comparative investigations of the right ventricle of the heart and its components in man and animals have proved to be essential not only for academic studies but also for therapeutic purposes and possible selection of the appropriate animal tissue for bioprosthesis in man (Harasaki et al., 1975; Icardo et al., 1993; Munro et al., 1995; Hayashi et al., 1996; Haroun et al., 1999; Nozynski et al., 2003).

The septomarginal trabecula of human right ventricle has been described as a curved muscle band that bridges from the lower part of the interventricular septum to the base of the anterior papillary muscle (Williams et al., 1995; Sinnatamaby, 1999). It carries the continuation of the right bundle branch of the conducting system of the heart. It was believed by earlier researchers that it prevented over distension of the right ventricle; hence its old name "the moderator band" (Sisson & Grossman, 1975). The trabecula septomarginalis was investigated, by Depreux et al. (1976), in some earthy mammals and its location, attachments and measurements were incompletely elucidated. In animals, the functions of the moderator band have been mentioned to support the right branch of the atrioventricular bundle and to contain a small artery originating from either of the coronary arteries (Depreux et al., 1976). Detailed knowledge of the anatomy, morphometry, structure and function of the trabecula septomarginalis in man and animals is still deficient in the available literature.

MATERIALS AND METHODS

Forty apparently healthy adult hearts were utilized in this work; 10 of each of human, Arabian camel (Camelus Dromedarius), Arabian Naimi sheep (Ovis Aries), and Arabian monkey (Papio Hamadryas). Each species group of specimens was composed of five male and five female hearts. The human hearts were obtained from the Anatomy Laboratory, College of Medicine, KFU, Dammam, KSA and their ages ranged from 35 to 65 years. The camel and lamb hearts were retrieved from Al-Dammam Slaughter House, KSA immediately after sacrifice and the animal ages and weights were 18-20 years and 300-350 kg (for camels), and 4-5 years and 22-25 kg (for sheep). The monkeys (aged 17-20 years and weighing 10-16 kg) were hunted and brought from the Southern Province of Saudi Arabia, anaesthetized and sacrificed by ether and thiopental; and their hearts were then excised.

In each heart, the right ventricle was incised along its right lateral wall, the walls were carefully retracted and the interior was thoroughly washed with saline. The septomarginal trabecula was grossly examined, described and photographed in situ.

In each heart of the four species groups, the length and circumference of the septomarginal trabecula were determined before and after its excision out of the heart using fine caliper, non-stretchable nylon thread and flexible metric ruler. All measurements obtained were recorded, tabulated and subjected to SPSS statistical program and Chi-Square test.

In each species, two excised trabeculae with adjacent ventricular walls were selected to get longitudinal and transverse histological sections. They were fixed in 10 % formol saline, routinely processed for paraffinblocks, sectioned at 7 um, stained with haematoxylin and eosin (H&E), Masson's trichrome (MT) and orcein stains, examined by the light microscope and then photographed.

RESULTS

A. Gross Anatomical And Histological Results:

A1.The septomarginal trabecula in Man (Figs. 1A & 2A):

Gross examination of the interior of the human right ventricle showed that the septomarginal trabecula was in the form of a shining small, thin and flattened band frequently duplicated particularly at its extremities. It extended from the septal wall of the ventricle at the base of one of the masses of the septal papillary muscle to the sternocostal wall of the right ventricle at the base of the anterior papillary muscle (Fig. 1-A). Apart from the smaller size of the heart and its components in females, no more magnificent gross sex-differences were observed in the human septomarginal trabecula.

Histological examination of the septomarginal trabecula of the human right ventricle revealed that it was structurally composed of a mass of ordinary myocardial fibres amongst which a faintly-stained fibrocellular tract was noted (Fig. 2-A). This tract was constituted of few clusters of cells that had less staining affinity than the ordinary myocardial cells. The concerned cellular tract was surrounded by bundles of many collagenous and few elastic fibres. The septomarginal trabecula also contained cross sections of a small-sized artery located in different positions along the course of the trabecula.

A2. The Septomarginal Trabecula In Camel (Figs. 1b & 2b):

The septomarginal trabecula of the camel heart appeared as a glistening, thick, and mostly rounded band that was always kinked unless the ventricular walls were stretched. It extended from the interventricular septum just distal to the muscle papillaris subarteriosus to the ventrolateral wall of the right ventricle at the base of the muscle papillaris magnus. At its extremities, the trabecula looked more flattened (Fig. 1-B). No significant morphological features were observed as sex-related differences in the trabecula of the camel heart.

The striking feature of the structure of the septomarginal trabecula of the camel right ventricle was the more linear cellular orientation and the increased thickness of the faintly stained fibrocellular tract amongst the ordinary myocytes (Fig. 2-B), when compared to the human trabecula (Fig. 2-A). The cells of this tract were arranged in clusters, lying edge to edge with a little intercellular substance, and acquiring a mosaic appearance. These

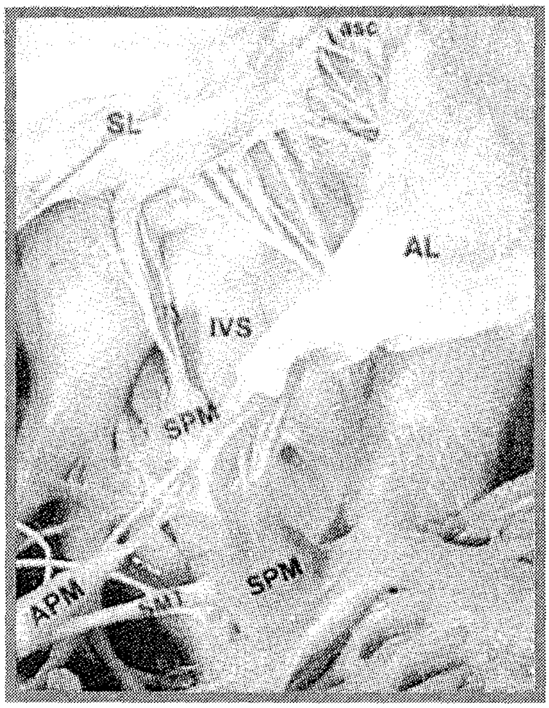

Fig. 1A

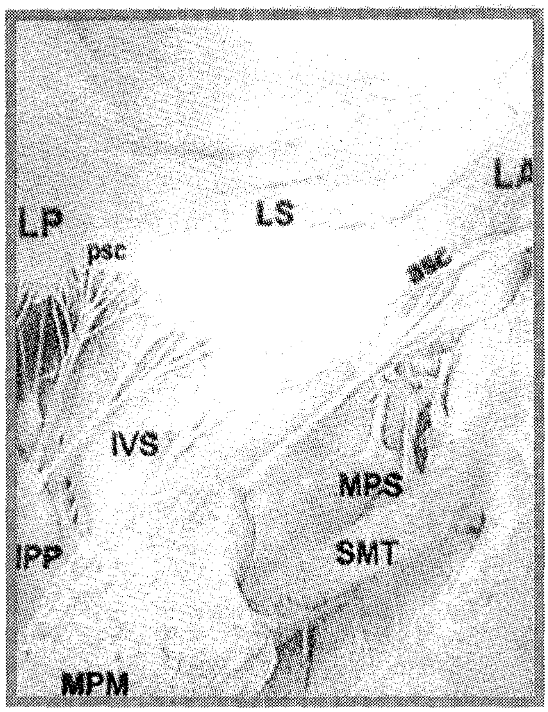

Fig. 1B

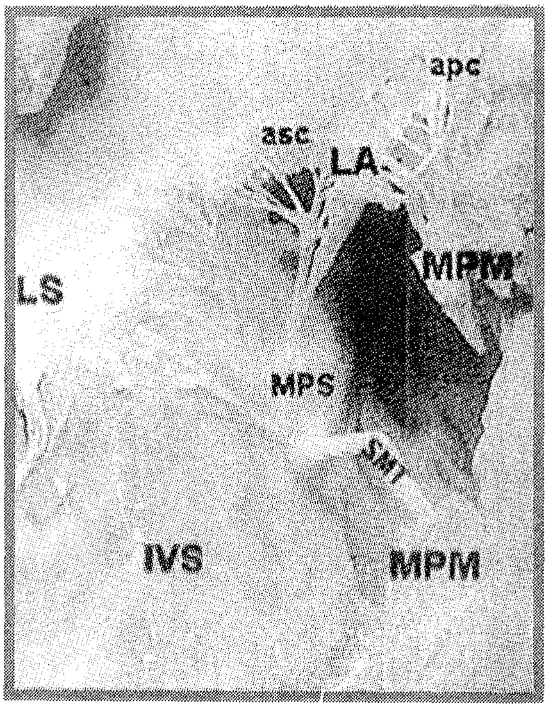

Fig. 1C

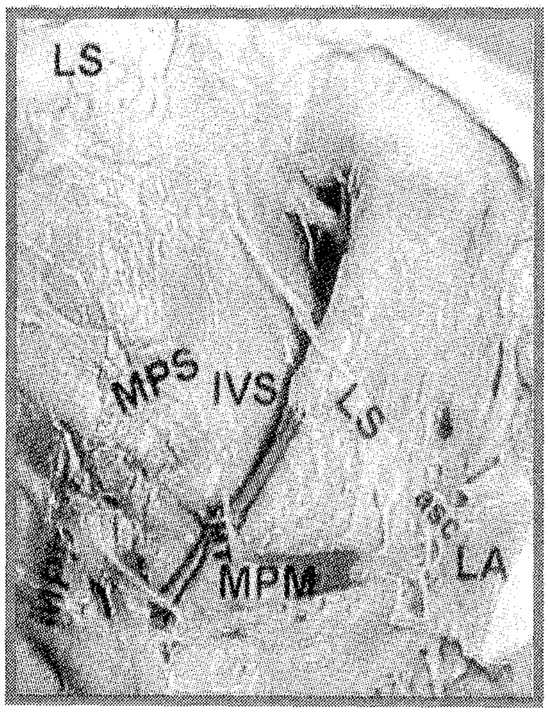

Fig. 1D

Figs. (1: A, B, C & D): Photographs of the interior of the right ventricles of adult male human (A), and Arabian camel (B), sheep (C), and monkey (D); showing the morphological features and extensions of their septomarginal trabeculae (SMT).
IVS: interventricular septum.
APM & SPM: human anterior and posterior papillary muscles.
MPM, MPS & MPP: muscles papillaris magnus, subarteriosus and parvi of animals.
AL & SL: anterior and septal leaflets of the human tricuspid valve.
LA, LP & LS: leaflets angularis, parietalis and septalis of the animal tricuspid valves.
asc: human anteroseptal (or animal anguloseptal) commissure of the valve.
apc & psc: anguloparietal and parietoseptal commissures of the animal valves.

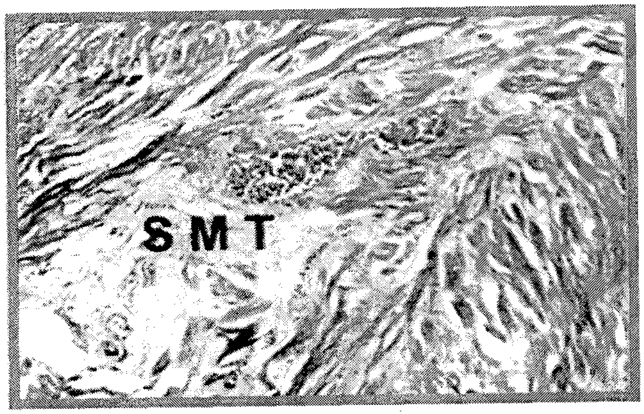

Fig. 2A

Fig. 2B

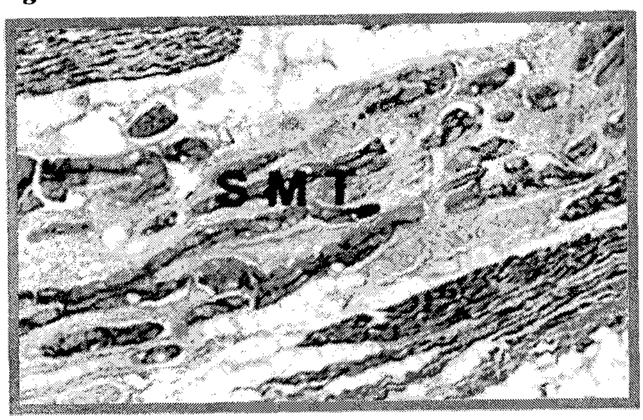

Fig. 2C

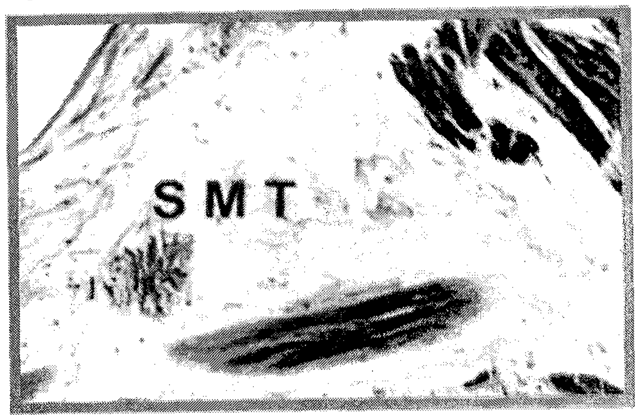

Fig. 2D

Figs.(2: A, B, C & D): Microphotographs of the septomarginal trabeculae (SMT) of adult male human (A), and Arabian camel (B), sheep (C), and monkey (D); showing the faintly stained fibrocellular path of the conducting system, bordered by ordinary myocardial fibres. The characteristic foamy and mosaic-like cellular content of the trabecula is the most obvious in sheep. Bundles of connective tissue fibres (greenish blue) are seen surrounding the clusters of the conducting cells. Sections of small blood vessels could be seen within the trabeculae. (Masson's trichrome; X 40)

conducting cells formed a plenty of cellular aggregates and they were more obviously foamy in appearance, larger in size, and more linear in succession than those of the human trabecula. These specialized myocytes were multinucleated with most of their nuclear material peripherally dispersed. Sections of a smallsized artery were also observed within the camel trabecula.

A3. The Septomarginal Trabecula In Sheep (Figs. 1c & 2c):

The septomarginal trabecula of the sheep heart was observed as a glistening moderately thick band. It looked rounded along its major middle part but flattened at its ends. It was also kinked unless the ventricular walls were retracted. It extended between the bases of the

Table (1): Measurements of the human septomarginal trabecula both sexes.

Measurements of the Septomarginal Trabecula of the Human Right Ventricle	Male			Female			
	Range (cm)	Mean (cm)	S.D. (±)	Range (cm)	Mean (cm)	S.D. (±)	Chi-Square Test
1. Length:	2.8-3.3	3.04	0.18	2.6-3.0	2.86	0.17	0.076
2. Circumference, Proximal:	2.6-3.1	2.84	0.23	1.8-2.3	2.12	0.19	0.050*
Distal:	2.2-2.6	2.42	0.15	1.5-2.1	1.80	0.22	0.048*

* $P < 0.05$ = Significant.

Table (2): Measurements of the camel septomarginal trabecula in both sexes.

Measurements of the Septomarginal Trabecula of the Camel Right Ventricle	Male			Female			Chi-Square Test
	Range (cm)	Mean (cm)	S.D. (±)	Range (cm)	Mean (cm)	S.D. (±)	
1. Length:	5.0-5.8	5.52	0.33	3.1-4.0	3.68	0.36	0.048*
2. Circumference,							
Proximal:	1.6-2.0	1.80	0.16	3.5-5.3	4.20	0.72	0.054*
Distal:	2.5-2.9	2.72	0.16	3.7-5.5	4.22	0.73	0.126

* P < 0.05 = Significant.

Table (3): Measurements of the sheep septomarginal trabecula in both sexes.

Measurements of the Septomarginal Trabecula of the Sheep Right Ventricle	Male			Female			Chi-Square Test
	Range (cm)	Mean (cm)	S.D. (±)	Range (cm)	Mean (cm)	S.D. (±)	
Length:	1.9-3.0	2.46	0.48	2.2-3.9	3.28	0.70	0.170
Circumference,							
Proximal:	0.7-0.8	0.72	4.47	0.7-1.0	0.86	0.11	0.170
Distal:	0.8-1.0	0.90	7.07	0.9-1.0	0.94	5.48	0.197

* P < 0.05 = Significant.

Table (4): Measurements of the monkey septomarginal trabecula in both sexes.

Measurements of the Septomarginal Trabecula of the Monkey Right Ventricle	Male			Female			Chi-Square Test
	Range (cm)	Mean (cm)	S.D. (±)	Range (cm)	Mean (cm)	S.D. (±)	
Length:	1.4-1.7	1.60	0.12	1.3-1.8	1.64	0.21	0.049*
Circumference,							
Proximal:	0.4-0.6	0.46	8.94	0.4-0.7	0.52	0.13	0.059
Distal:	0.5-0.6	0.52	4.47	0.5-0.7	0.62	8.37	0.285

Table (5): Measurements of the septomarginal trabecula in man and camel

* P < 0.05 = Significant.

Measurements of the Septomarginal Trabecula	Man			Camel			Chi-Square Test
	Range (cm)	Mean (cm)	S.D. (±)	Range (cm)	Mean (cm)	S.D. (±)	
1. Length:	2.6-3.3	2.91	0.22	3.1-5.8	4.14	0.89	0.006*
2. Circumfer ence,	1.8-3.1	2.48	0.43	1.6-5.3	3.00	1.36	0.032*
Proximal:	1.5-2.6	2.11	0.37	2.5-5.5	3.47	0.94	0.111
Distal:							

* P < 0.05 = Significant.

Table (6): Measurements of the septomarginal trabecula in man and sheep

Measurements of the Septomarginal Trabecula	Man			Sheep			Chi-Square Test
	Range (cm)	Mean (cm)	S.D. (±)	Range (cm)	Mean (cm)	S.D. (±)	
Length:	2.6-3.3	2.91	0.22	1.9-3.9	2.82	0.88	0.113
Circumference:							
Proximal:	1.8-3.1	2.48	0.43	0.7-1.0	0.79	0.11	0.316
Distal:	1.5-2.6	2.11	0.37	0.8-1.0	0.92	0.06	0.799

* P < 0.05 = Significant.

Table (7): Measurements of the septomarginal trabecula in man and monkey

Measurements the Septomarginal Trabecula	Man			Monkey			Chi-Square Test
	Range (cm)	Mean (cm)	S.D. (±)	Range (cm)	Mean (cm)	S.D. (±)	
Length:	2.6-3.3	2.91	0.22	1.3-1.8	1.62	0.16	0.019*
Circumference,							
Proximal:	1.8-3.1	2.48	0.43	0.4-0.7	0.49	0.11	0.788
Distal:	1.5-2.6	2.11	0.37	0.5-0.7	0.57	0.08	0.466

* P < 0.05 = Significant.

muscles papillaris subarteriosus and magnus (Fig. 1-C). The morphology of the trabecula of the sheep heart was the same in both sexes.

Microscopy of the septomarginal trabecula of the sheep (Fig. 2-C) proved to be similar to that of the camel. The mosaiclike foamy cells in the core of the trabecula were more conspicuous and highly featured than those of other species.

A4. The septomarginal trabecula in Monkey (Figs.1& 2D):

The septomarginal trabecula of the monkey right ventricle was grossly demonstrated as a short, straight, moderately broad and flattened band that bridged between the interventricular septum, away from the muscle papillaris subarteriosus, to the base of the muscle papillaris magnus. Some chorda-like connections were seen linking the bases of the muscles papillaris magnus and parvi (Fig. 1-D). Morphological sex-differences were not also observed in monkey trabecula.

The fibrocellular faint path of the septomarginal trabecula of the monkey (Fig. 2-D) was less developed and poorer in cells and connective tissue fibres than that of the other two animal species investigated.

B. Morphometric Results (Tables 1-7):

The different measurements of the human septomarginal trabecula showed significantly lower mean values in females than in males except for the length of the trabecula that revealed statistically insignificant lower female values (Table 1).

The measurements of the animal septomarginal trabeculae displayed significantly higher mean values in females than in males regarding the proximal circumference of the trabecula in camel (Table 2) and the length of the trabecula in monkey. The length of the camel trabecula was significantly shorter in females than in males (Table 2). All the measurements of the sheep trabecula and the circumference of the monkey trabecula were insignificantly higher in females than in males (Table 3 & 4).

Comparing human and animal trabeculae, the trabecular length of the Arabian camel was significantly longer and that of the Arabian monkey was significantly shorter than that of the human trabecula. The rest of the correlated human and animal trabecular measurements showed insignificant differences (Tables 5-7).

DISCUSSION

The human septomarginal trabecula or septal band forms the lower limit of the trabecular inflow tract of the right ventricle. It is variably developed in different hearts, yet it deserves special mention as it serves to convey the continuation of the right bundle branch of the specialized conducting tissue of the heart (Williams et al., 1995; Sinnatamby, 1999). In the present study, the human trabecula proved to have a smooth surface as it was sleeved with endocardium. It was small, thin and flattened. It always stretched between the lower part of the interventricular septum and the base of the anterior papillary muscle. The current course of the human trabecula septomarginalis coincides with the subendocardial course of the right bundle branch mentioned in the literature. Its observed smaller size in human hearts than in hearts of other species could lead to the proposal that the trabecula is morphologically more developed in animals. The current observation that the human trabecula was frequently duplicated at its extremities is in accordance of the report that it usually divides into limbs embracing the base of the septal papillary muscle to support the septal wall of the right ventricle (Williams et al., 1995). In the present investigation, no significant sex-differences were observed in the human trabeculae.

The right bundle branch of the cardiac conducting system is described, in textbooks of Anatomy, to run a septal myocardial then a subendocardial course before it traverses the trabecula septomarginalis. When this bundle branch reaches the base of the anterior papillary muscle, via the trabecula, it breaks into a rich plexus of subendocardial fibres that spread towards ventricular walls. The transitional myocytes of the atrioventricular node and bundle of His are reported to continue into the bundle branches and finally into the subendocardial networks (Williams et al., 1995; Sinnatamby, 1999). These cells gradually increase in size as they run distally till they acquire the characteristics of Purkinje myocytes. Between and around these cells lie the ordinary cardiac myocytes. In the present investigation, a faintly stained fibrocellular tract has been demonstrated in the structure of the human septomarginal trabecula. The cells of this tract are larger than those of the surrounding myocardium. They are also marginally multinucleated, lying edge to edge, arranged in parallel clusters and increasing in size as the trabecula approaches the base of the anterior papillary muscle. The cells are surrounded by many collagenous fibres, few elastic fibres, and ordinary myocardial fibres. As these specialized cells are known to be faster in conduction, their relative larger size, than the ordinary myocytes observed herein, appears to be function-related. The present study gives a detailed morpho-histological description of the specialized conducting tissue in the human and animal septomarginal trabeculae that has not been yet fully revealed in the available literature.

Furthermore, the present investigation has demonstrated sections of a small-sized artery within the septomarginal trabecula of each species investigated. These arterial sections are aligned along the sides of the running axis of the trabecula. This leads to the hypothesis that such a trabecular artery is tortuous in course in order to cope with the tension imposed on it when the right ventricle is distended during diastole. This finding is partially consistent with the report of Melo et al. (1995) who found 1-3 large septal arteries in postmortem human hearts; one of these arteries was always located in the lower border of the anterior limb of the septomarginal trabecula. This also leads to the conclusion that the trabecula septomarginalis serves to convey a blood supply to a part of the ventricular walls.

Parts of four rings of a specialized myocardium in the regions of transition between the components of the primitive heart tube were thought to be responsible for the development of the conducting system in man and mouse. Such a four-ring concept explains the variations in the conducting system met in hearts of certain animals and in malformed human hearts (Wenink, 1976). Other investigations failed to detect anatomical species-differences between murine and human conducting systems of the heart (Molina et al., 1988). Isomers of lactate dehydrogenase (LDH) enzyme are reported to be present in species-specific varying amounts in the myocardium and conducting system tissues of man, cattle, sheep and pig (Herrmann et al., 1994). These controversial points in the reviewed literature had urged us to investigate the trabecula in man and Arabian camel, Naimi sheep, and monkey. The animals investigated herein had never been the targets of previous cardiac morphometric investigations. In the current work, except in the monkey, the animal trabeculae morphologically looked thicker than the human one; being the thickest in the camel. They were always glistening since they were covered with endocardium. Except in the monkey, the animal trabeculae always appeared curved or kinked suggesting their possible role in preventing over distension of the right ventricle during diastole. In these animals investigated, the trabeculae extended from the interventricular septum distal to the muscle papillaris subarteriosus to the ventrolateral wall of the right ventricle at the base of the muscle papillaris magnus; approximately the same extensions as the human trabecula. The muscles papillaris magnus, subarteriosus and parvi in the right ventricles of animals functionally correspond to the human anterior, septal and posterior papillary muscles respectively (Nickel et al., 1981). The leaflets angularis, parietalis and septalis of the animal tricuspid valve are the homologues of the human anterior, posterior and septal leaflets respectively (Sisson & Grossman, 1975; Nickel et al., 1981).

The minute structure of the septomarginal trabeculae in the investigated Arabian camel and sheep revealed the faint fibrocellular tract of specialized myocytes to be more linear and thicker than those of human and monkey hearts. The cells of the animal tract were larger, and more clearly featured and foamy than the human cells. These cells were the best obvious in the sheep trabeculae. The monkey conducting cells were the least evident in the three animal species. The current findings support the concept that structural species-differences of the septomarginal trabecula do exist and the trabecula is more developed in some animals than others. These findings need to be functionally extended in further investigations. Bytzer (1979) observed that the myofibrils in the Purkinje fibres (P-fibres) of the porcine septomarginal trabecula exhibited a nearly parallel arrangement while in the septal walls of the ventricles they acquired a cart-wheel alignment. The latter authors attributed such arrangements to the degree of mechanical tension imposed on the P-fibres in these two different locations. Consistent with Bytzer's findings, the present study demonstrated a linear arrangement of the specialized myocytes in the trabecula septomarginalis particularly in camel and sheep. Armiger et al. (1979) demonstrated extracellular foci of fat droplets in the septomarginal trabeculae of adult dog hearts. These authors also observed considerable age-changes in the fine structure of the Purkinje cells as they were cuboidal resembling typical conducting cells in puppies while they were elongated resembling working myocytes in adult dogs. The fibrous content of the trabeculae became more developed with maturation of the dogs. In the present study, the foamy and mosaic appearance of the conducting cells of adult human and animal trabeculae suggests intracellular accumulation of fat droplets that dissolved during histological preparation of the specimens. The conducting cells, investigated herein, are surrounded by many collagenous fibres, few elastic fibres, and ordinary myocardial fibres.

The current study has clarified the functions of the trabecula septomarginalis, in man and animals, on the basis of its morphology and structure as: to convey the right bundle branch of the conducting system of the heart, to carry a tortuous artery supplying parts of the ventricular walls, and to help in prevention of over distension of the right ventricle during its relaxation. The present research hopefully looks for the possibility of usage of some of these animal specialized myocytes in the development of tissue-engineered cardiac conducting cells. A part or whole of the animal trabecula might be also successfully chosen for animal or human cardiac reconstructive surgeries.

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