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The anatomy of the tendon of the Infundibulum revisited

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The heart is a muscular organ supported by collagenous tissue. The collagenous tissue is condensed in certain areas to form a supporting framework, often called the fibrous skeleton. The so-called tendon of the infundibulum has previously been described as part of this skeleton, but its structure and incidence remain ill defined. The tendon was initially described as a strip of fibrous tissue running between the aortic root and the pulmonary trunk. Since information on its structure is vague, we sought to evaluate its existence in 100 formalin-fixed adult human hearts obtained from subjects ranging in age from 22 to 86 years, in 20 hearts from infants and children aged from 2 months to 6 years at the time of their death and in 10 cattle hearts. We used classical macroscopic anatomical techniques to demonstrate all the possible connections between the sinuses of the aorta and the pulmonary trunk. We then supplemented the macroscopic techniques with serial transverse histological sections taken through the vascular roots, staining the sections with the haematoxylin-eosin, van Gieson, Masson trichrome and orcein staining methods. Fascial bands surrounded by connective tissue were observed in all hearts. In 80 adult hearts and in 16 neonatal hearts we found fascial bands or strips, which connected the aortic and pulmonary roots. Only in two hearts, however, were we able to identify tendon-like structures, and histology revealed that these were formed by tightly packed collagen fibres intermingled with fat, most likely due to advanced age. Thus in those cases where a "tendon" was present it was no more than condensed fascial bands joining together the apposing sinuses of the arterial trunks. In our opinion, therefore, accounts in the literature describing the "tendon of the infundibulum" as a tendinous structure connecting the aortic and pulmonary roots do not accurately represent this anatomical structure.

Key words: aortic root, pulmonary root, fibrous skeleton, fascial bands, heart, arterial trunks

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INTRODUCTION

Knowledge of normal cardiac anatomy is indispensable for the proper understanding of cardiac disease. Despite centuries of study, however, several structures within the heart remain enigmatic and incompletely understood. One of these structures is the so-called tendon of the infundibulum. Although its presence between the aortic and pulmonary roots is noted in medical textbooks and atlases [11, 12, 15, 16], recent studies [2, 4, 5, 9] have suggested that the purported tendon is an inconstant structure. To our knowledge, it was Mall [7] who first described the tendon, although he suggested that it had previously been recognised by Krehl. Mall named it the "conus tendon" [7]. Nonetheless, to date no clinical significance has been attributed to this structure. The question must be raised as to whether the tendon of the infundibulum exists in the normal human heart. To resolve this dilemma we have studied 120 human hearts taken from subjects from infancy to old age and also 10 cattle hearts, seeking to establish the presence or absence of the tendon or its rudiment.

MATERIAL AND METHODS

Macroscopic analysis

We studied 100 adult human hearts and 20 hearts from infants and young children collected during autopsies performed at the Department of Pathology at the Institute of Rheumatology and the Department of Forensic Medicine of Warsaw Medical University. The hearts were derived from 55 female and 65 male subjects, all of whom had died from non-cardiovascular causes, and revealed no macroscopic pathological abnormalities. The age at death of the adults ranged from 22 to 86 years, with a mean of 72 years, while the younger subjects were aged from 2 months to 6 years at the time of death, with a mean of 4 months. In addition, 10 cattle hearts were dissected. All specimens had been prosected and fixed in 10% formalin and alcohol phenol solution. Following preliminary examination, the perivascular fatty tissue was carefully removed where necessary in order to visualise the space between the aorta and pulmonary trunk. All specimens were then dissected at the level of the sinutubular junction [13], separating the aortic and pulmonary sinuses to reveal any fibrous structures between them. For histological comparison with structures potentially representing the tendon of the infundibulum we examined ten tendons taken from the histological museum at the Department of Pathology at the Institute of Rheumatology in Warsaw, Poland from the insertion of the biceps brachii.

A preliminary examination was performed, after which images from all the dissected specimens were recorded with a Sony digital camera (model: Sony Cyber-Shot DSC-f717) and studied using a computer-assisted image analysis system. All measurements were carried out with the Lucia program (1998 edition for Windows), made by Nikon (Laboratory Imaging Ltd., Precoptic Co., Medical and Optical Instruments, Poland). The digital camera was connected to an image processor (Nvidia Riva TNT model 64) with linkage to a mainframe computer. Digitised images of the aortic and pulmonary roots, together with their surrounding vessels and structures, were stored in the Lucia program (1152 × 864 pixels) and converted to grey levels in the intensity range of 0 (darkest) to 32 bit (lightest). After applying a standard 1 mm scale to all pictures within the program, Lucia was able to use this information to calculate pixel differences between two selected points, such as the origin and termination of the fascial bands. The purpose of the software was to allow easy and accurate translation of pixel differences into metric measurements as previously described [6]. We were able to record the origin and insertion of any fascial bands. The position of each band was analysed in relation to the sinutubular junction and described as being above, below, or at the junctional level. Special care was taken during the dissection to capture images from different points of view so as to avoid missing any small or fine structures.

Microscopic analysis

In 20 hearts, 15 from adults and 5 from infants, we made serial transverse histological sections through the arterial roots, with the plane of section running approximately perpendicular to the aortic axis, cutting the sections at a thickness of 5 microns. The sections extended to the proximal attachments of the valvar leaflets of the aorta within the ventricles.

Sections were made in paraffin-embedded specimens and stained with the haematoxylin-eosin, van Gieson, Masson trichrome and orcein staining methods and were examined in order to detect any fibrous bands or structures connecting the aortic and pulmonary roots in the location initially described by Mall [7].

Figure 1. The arrow indicates a discrete fibrous fascial band joining the aortic and pulmonary roots. Such fascial bands extend above the level of the sinutubular junction in close proximity to the origin of the right coronary artery.

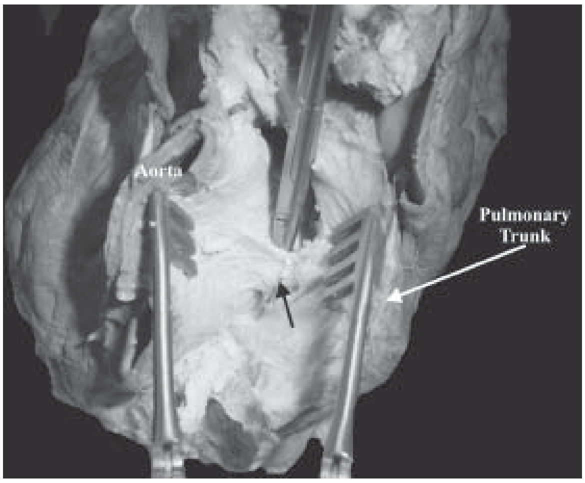

Figure 2. The picture demonstrates a discrete fibrous fascial band joining the aortic and pulmonary roots in a specimen of cow heart.

RESULTS

In 80 (80%) of adult specimens and in 16 (80%) of the hearts from the younger subjects it was possible to find discrete fibrous fascial bands, both macroscopically and histologically, that extended between the aortic and pulmonary roots (Fig. 1). At the aortic side the bands were attached mostly above or at the level of the sinutubular junction, being in close proximity to the origin of the right coronary artery and extending to the opposing external wall of the pulmonary trunk. These bands ran from the adventitial wall of the aorta at the top of the interleaflet triangle between the left and the right coronary sinuses and extended to the wall of the pulmonary trunk just to the left side of the top of the interleaflet triangle between the right and left facing sinuses. We were unable to trace any fibrous structures into the musculature of the subpulmonary infundibulum, all bands being confined to the tissue plane between the two arterial roots. In the remaining 22 specimens we did not observe any discrete structures that were comparable with the specimens just described, finding only random fascial attachments between the aortic and pulmonary roots.

The fibrous bands were generally short, ranging from 4 to 16 mm in length, with a mean of 10 mm, and resisted mechanical separation of the vessels. The remainder of the space between the aortic and pulmonary roots was occupied in almost all specimens by adipose tissue intermingled with collagen fibres.

The cattle hearts exhibited similar morphology to the human hearts. Distinct fibrous bands were identified in 7 of the specimens (Fig. 2). In the remaining specimens fascial bands were present.

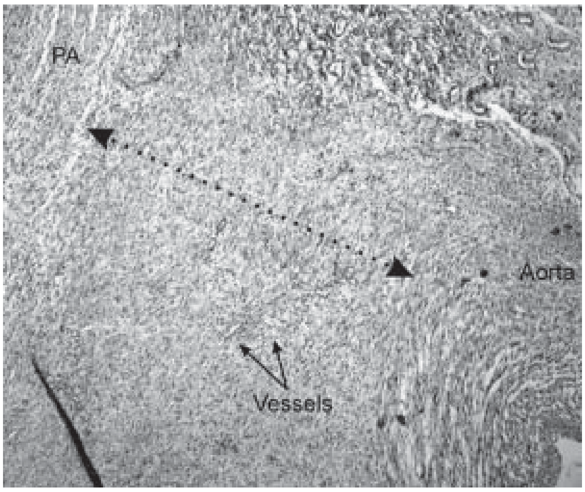

Figure 3. The adventitial layers of the aortic and pulmonary roots are tightly connected with abundant collagen fibres. Masson trichrome × 10.

Histologically, the fibrous bands were composed of connective tissue fibres, which extended from the adventitia of the wall of the aorta to that of the pulmonary trunk. In only two of our specimens were the fascial bands sufficiently compact to resemble the initial description given by Mall [7]. In these cases the adventitial walls of both arterial roots were tightly connected and continuous with the collagen fibres of the fibrous band (Fig. 3). The band was penetrated by small nerves and vessels and had some characteristics of the structure of a tendon (Fig. 4A), although a comparison with the tendon of the

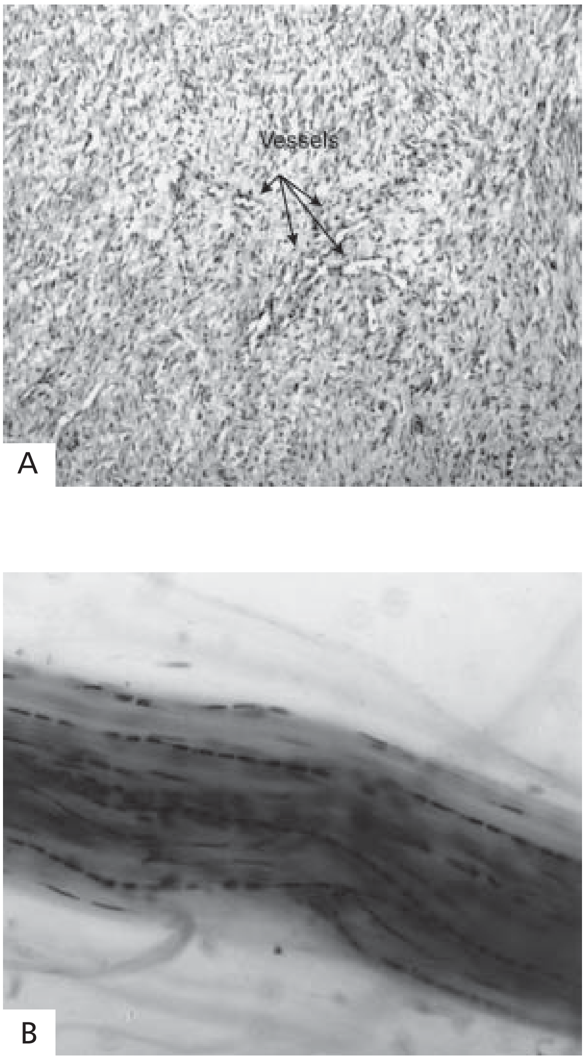

Figure 4. At multiple locations along the fascial band (**A**) it was penetrated by many vessels and nerves, giving it some resemblance to a tendon. It bears no resemblance, however, to the biceps brachii tendon (**B**). HE × 20.

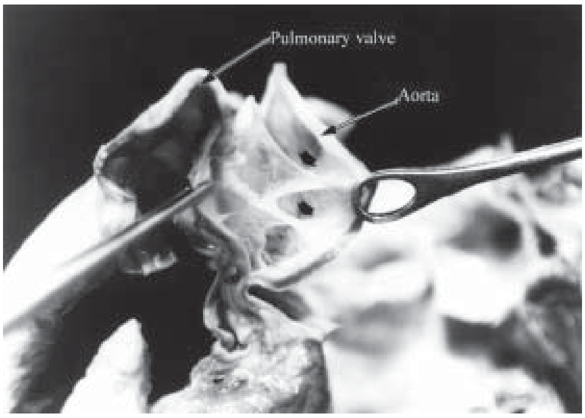

Figure 5. Arrows indicate the loose fascial bands which are present in almost all the specimens, although not arranged in any particular location.

biceps demonstrated an obvious difference between these structures (Fig. 4B).

Our histological and macroscopic analyses revealed that the density of the fascial bands increased with age. Thus in the elderly the fascial bands could be tightly packed and intermingled with adipose tissue to produce tendon-like structures. Loose fascial bands (Fig. 5) were found in almost all the specimens, although they were not arranged in any particular location or manner. Histological examination confirmed the presence of these bands as small structures connecting the facing sinuses of the aorta and pulmonary trunk (Fig. 6).

DISCUSSION

To the best of our knowledge, it was Mall [7] who first described the "tendon of the infundibulum"

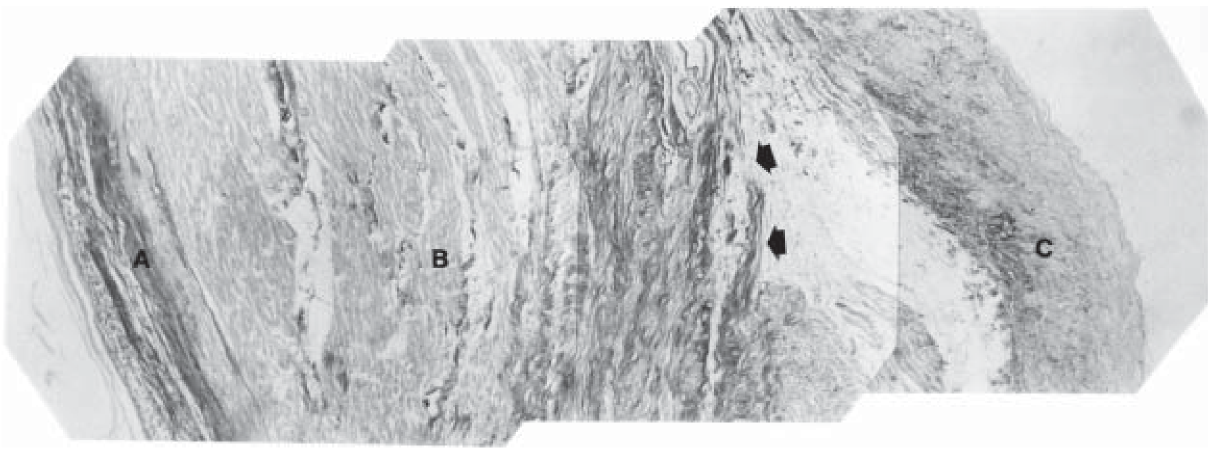

Figure 6. The histological sections confirm the macroscopic observations; **A.** Aorta, large arrows: vessels, small arrows: fascial bands; **B**. Space between aorta and pulmonary trunk filled with fat; **C.** Pulmonary trunk.

as part of the fibrous skeleton of the heart. According to Mall [7], this tendon had previously been recognised by Krehl and named the "conus tendon". In giving surgical significance to the structure as part of the fibrous skeleton of the heart Zimmerman and Bailey [18] argued that the tendon functioned as a rope between the aortic and pulmonary roots. They stated that it permitted a certain degree of torsional movement between the roots, while preventing them from being torn apart by the differentially directed expulsive forces of the ventricles. Their review, however, was not accompanied by macroscopic or histological evidence to prove the existence of the tendon. Their conclusions were perhaps surprising, since Kerr and Goss [3] had examined the interspace between the pulmonary and aortic valves in 200 heart specimens and did not mention the presence of any "tendon of the infundibulum". Following Zimmerman and Bailey [18], Walmsley and Watson [14] also illustrated the fibrous skeleton of the heart as including the so-called "conus tendon", which they described as a strip of tendinous fibrous tissue. As far as we are aware, it was McAlpine [8] who subsequently called the existence of the tendon into question, describing the connective tissue between the aortic and pulmonary roots accurately as fascial bands.

Our current study demonstrates unequivocally that the structures we observed between the arterial roots fail to correspond to the classic microscopic description of the tendon of a muscle. According to Montes et al. [10], a tendon is a white shiny fibrous cord, varying in length and thickness, sometimes round and sometimes flattened, and devoid of elasticity. The most common type of dense connective tissue, and the densest form of collagenous tissue, is that of the tendon. It consists almost entirely of white fibrous tissues, the fibrils of which have an undulating course and which are firmly united. These bundles are separated by a small quantity of amorphous intracellular substance. The collagen bundles of tendons aggregate into larger bundles that are enveloped by loose connective tissue containing blood vessels and nerves. Externally, a tendon is surrounded by a sheath of dense connective tissue. When boiled in water the tendon is almost completely converted into gelatin, the white fibres being composed of the albuminoid collagen, which is often regarded as the anhydride of gelatin.

Our histological analysis, in contrast, revealed that the structures found to bind the arterial roots together were composed of loose connective and fatty tissues. We hypothesise that the function of these fascial bands is to bind the aortic and pulmonary roots together, while allowing a considerable amount of movement to take place because of their innate elasticity. In the event of a true tendon being attached between the aortic and pulmonary roots, the amount of movement would be limited, especially in situations of increased pressure. Another possible function for these bands is that of a mechanical shock-absorber. In this context, therefore, it may be pertinent that in some regions the loose framework of connective tissue and the fatty tissue also contain large amounts of elastic tissue capable of absorbing mechanical forces.

Our findings, therefore, lend no support to the definition of the "tendon of the infundibulum" as given by Mall [7] but rather endorse the view of McAlpine [8] that the so- called "tendon" is no more than a collection of fascial bands or sheets binding the aortic and pulmonary roots together and that this structure should not be described as a true tendon.

As with our current investigation, Lal et al. [4] were similarly unable to detect any tendinous fibrous structure connecting the aortic and pulmonary roots, although they found one specimen in which the fascial bands were condensed into a firmer fibrous strip. The presence of these inconstant fibrous strips was then endorsed by Merrick et al. [9], who found such bands in only half the hearts they studied at autopsy or during surgery. Hokken et al. [2], also searching for the enigmatic "tendon", found it to be present in only 2 out of 9 specimens examined. They described the tendon as a "collagenous condensation", which again fits very well with our current descriptions and findings. They borrowed a name from Zimmerman [17, 18] and named it the "third body", rather than the tendon of the infundibulum. The third body as described by Zimmerman [17, 18], however, is continuous with the anterior part of the membranous septum, whereas the fascial bands as identified in our material never approximated to the membranous septum.

It is of interest that older editions of Gray's Anatomy [15] contain illustrations of the fibrous skeleton of the heart, including the conus tendon (Fig. 6.47, 6.48). In the description given in this edition, the "tendon of the infundibulum" is held to connect the pulmonary "annulus" and muscular infundibulum posteriorly to the root of aorta, extending to blend with the wall and margin of the right posterior non-coronary sinus and blending inferiorly with the membranous part of the ventricular septum. To emphasise this point again, we were unable during our current dissections to identify any connection between the membranous septum and the fascial bands noted above.

In the more recent edition of Gray's Anatomy [1] the text concerning the tendon of the infundibulum has been revised, but the Figure 10.52 has not been changed from the previous editions, still clearly indicating the presence of a so-called "tendon of the infundibulum". The same is also true of the 38th American edition of Gray's Anatomy [16], in which the tendon is described as the "conus tendon" (p. 636, Fig. 7.32).

Finally, our study is the first to explore the anatomy of the tendon of the infundibulum in animal and human hearts.

CONCLUSIONS

On the basis of recent studies, confirmed by our own current findings, we question whether there is any justification for the description of a "tendon of the infundibulum". At best, this structure is no more than a condensation of fascial bands between the apposing surfaces of the aortic and pulmonary valvar sinuses. It appears to be of no functional significance, since it is divided with impunity when encountered during surgical procedures, especially in the Ross procedure [2, 9]. The use of the terms "tendon" or "ligament of the infundibulum" should be systematically avoided.

REFERENCES

1. Carmine D. Clemente (eds) (1985) Skeleton of the heart. In: Gray's anatomy. Churchill Livingstone, New York, pp. 1494.
2. Hokken RB, Bartelings MM, Bogers JJ, Gittenberger-de Groot AC (1997) Morphology of the pulmonary and aortic roots with regard to the pulmonary autograft procedure. J Thor Cardiovasc Surg, 13: 453–461.
3. Kerr A, Goss CM (1956) Retention of embryonic relationship of aortic and pulmonary valve cusps and a suggested nomenclature. Anat Rec, 125: 77–82.
4. Lal M, Ho SY, Anderson RH (1997) Is there such a thing as the "tendon of the infundibulum" in the heart? Clin Anat, 10: 307–312.
5. Loukas M, Dimopoulos C, Bartczak A, Kordula J, Wagner T, Fudalej M (2001) The anatomy of the tendon of infundibulum. Folia Morphol, 60: 281–284.
6. Loukas M, Hullet J, Wagner T (2005) The clinical anatomy of the inferior phrenic artery. Clin Anat, 18: 357–362.
7. Mall FP (1911) On the muscular architecture of the ventricles of the human heart. Am J Anat, 11: 211–266.
8. McAlpine WA (1975) Heart and coronary arteries. Springer-Verlag, Berlin, Heidelberg, p. 72.
9. Merrick AF, Yacoub MH, Yen Ho Sy, Anderson RH (2000) Anatomy of the muscular subpulmonary infundibulum with regard to the Ross procedure. Ann Thorac Surg, 69: 556–5561.
10. Montes G.S. Ruggieri A, Motta PM Martinus Nijhoff (eds) (1984) Collagen distribution in tissues. In: Ultrastructure of the Connective Matrix. Springer-Verlag, Berlin, Heidelberg, pp. 35.
11. Netter FH (1969) The Ciba collection of medical illustrations. Heart, 5: 11.
12. Pomerance A, Davies MJ (1975) The pathology of the heart. Blackwell Scientific Publications, Oxford, pp.13.
13. Reid K (1970) The anatomy of the sinus of Valsalva. Thorax, 25: 79–85.
14. Walmsley T, Watson H (1978) In Clinical Anatomy of the Heart. Churchill Livingstone, Edinburgh, p. 111.
15. Williams PL, Warwick R, Dyson M, Bannister LH (eds) (1989) Skeleton of the heart. In: Gray's anatomy. 37th Ed. Churchill Livingstone, New York, pp. 716–717.
16. Williams PL, Bannister LH, Berry MM, Collins P, Dyson M, Dussek JE, Fergusson MWJ (eds) (1995) Skeleton of the heart. In: Gray's anatomy. 38th Ed. Churchill Livingstone, New York, pp. 1494–1495.
17. Zimmerman J (1960) The functional and surgical anatomy of the aortic valve. Am Heart J, 99: 217–224.
18. Zimmerman J, Bailey CP (1962) The surgical significance of the fibrous skeleton of the heart. J Thor Cardiovasc Surg, 44: 701–712.