CVJ CLUJ VETERINARY JOURNAL

Article

Distribution and functional significance of muscle islands in the tunica media of the aorta in the goat (*Capra hircus*)

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Abstract: The presence of muscle islands in the tunica media of elastic arteries has been reported in both large and small ruminants. According to some authors, these islands can have a certain influence on the physical-mechanical properties and the pattern of diseases in the aortic wall. The aim of the current study was to highlight the muscle islands and their distribution throughout the aortic segments in the goat and to understand the reason why they are present only in certain species of animals, including the goat. Gross anatomical dissection of the aorta was performed and samples from the following segments were harvested for histological investigations: ascending aorta, aortic arch, descending thoracic aorta and descending abdominal aorta. The muscle islands in the wall of the aortic segments are formed by smooth muscle cells interconnected with connective tissue and are preferentially vascularized by vasa vasorum and innervated by nervi vasorum. The aorta in the goat presents polymorphic muscle islands, arranged in the outer two thirds of the tunica media in the ascending aorta, the outer half at the level of the aortic arch and the descending thoracic aorta, but they are absent in the descending abdominal aorta. Their presence completes the windkessel function of the aortic wall, thus constituting an additional pump necessary to propel the blood towards the abdominal viscera, which in goats, in addition to those present in monogastrics, also contain three large and very active organs, namely the rumen, the reticulum and the omasum.

Keywords: goat, aorta, tunica media, muscle islands

Received: 13 December 2023
Accepted: 14 February 2024
Published: 9 April 2024

DOI:10.52331/z3nc1197

1. Introduction

During ventricular systole, blood is forced into the aorta in the form of intermittent jets, so it exerts a certain pressure on the vascular walls. Due to this pressure, the elastic structures in the wall of the arteries expand and store part of the pressure exerted on them, causing the dilation of the arterial lumen, to take over the surplus blood that arrives here during the ventricular systole. During diastole, the elastic fibers passively contract and return to their original size, causing excess blood to propel to the next segments. In this way, the elastic fibers produce what is called the windkessel effect during ventricular systole and diastole [1]. The muscle cells existing between the elastic lamellae complement the action of the elastic fibers through active contraction, so that through the action of the elastic and muscular components, blood flow becomes continuous in the following vessels [2].

In elastic arteries, the thickest tunic is the media containing the concentric elastic lamellae, between which there are circularly arranged smooth muscle fibers, collagen fibers, and reticular fibers [3]. These components have a particular arrangement among the elastic lamellae, which ensures their participation in completing the windkessel mechanism. In lower pressure arteries such as the abdominal descending aorta, the windkessel mechanism is complemented by a prominent internal elastic limiter [4].

In some species of mammals, the muscle component in the middle of the elastic arteries appears significantly better represented and with a particular disposition. Thus, [5] found that in the goat, the tunica media of the ascending aorta, the aortic arch and the descending thoracic aorta, present two areas: the luminal elastic area, which has a structure comparable to that of elastic arteries from other species, and the adventitial musculo-elastic area, in which elastic lamellae are zonally interrupted by polymorphic muscle islands. The presence of muscle islands in the tunica media of elastic arteries has been reported in both large and small ruminants [6-9]. According to some authors, these islands can have a certain influence on the physical-mechanical properties and the pattern of diseases in the aortic wall [9]. The aim of the current study was to highlight the muscle islands and their distribution throughout the aortic segments in the goat and to understand the reason why they are present only in certain species of animals, including the goat.

2. Materials and Methods

The biological material used in this study was represented by 5 adult goats, of common breed, slaughtered for consumption in a CE approved slaughterhouse. The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Bioethics Committee of the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, nr. 403 from 29.09.2023. The AVMA guidelines set criteria for euthanasia were followed, and the procedure was in line with the recommendations of the permanent OIE (World Organisation for Animal Health) Animal Welfare Working Group for Humane slaughter of animals.

Gross anatomical dissection of the aorta was performed and samples from the following segments were harvested for histological investigations: ascending aorta, aortic arch, descending thoracic aorta and descending abdominal aorta. The samples were fixed in 10% formalin solution for 7 days, then dehydrated in three successive baths of ethyl alcohol (70%, 96%, and absolute), clarified with three baths of 1-Butanol and embedded in paraffin. Sections with a thickness of 5 μm were made, which were stained by the Trichrome Goldner method. The obtained preparations were examined under an Olympus BX41 microscope, equipped with a digital camera for capturing images, model Olympus E-330.

3. Results

The first segment of the arterial system at the exit from the heart is the ascending aorta, which in the goat has a very peculiar wall structure, differing in some respects from that of most mammals. These particularities are found in the media, while the intima and adventitia are comparable to the existing situation in other mammals. The particularity consists in the fact that the ratio between the elastic and the muscular component is different here and the disposition of the muscular component has some particularities. In the media of the ascending aorta of the goat, two areas can be distinguished, an internal one that occupies approximately 40% of the wall thickness that has the appearance found in the elastic arteries of other mammalian species, and an external one that occupies approximately 60% of the wall thickness in which the muscular component it is much better represented compared to the intima. Here the muscle component forms islands arranged at a certain distance from each other, without respecting a rigorous distribution. Islets are polymorphic in both shape and size and even muscle cell orientation (Fig. 1).

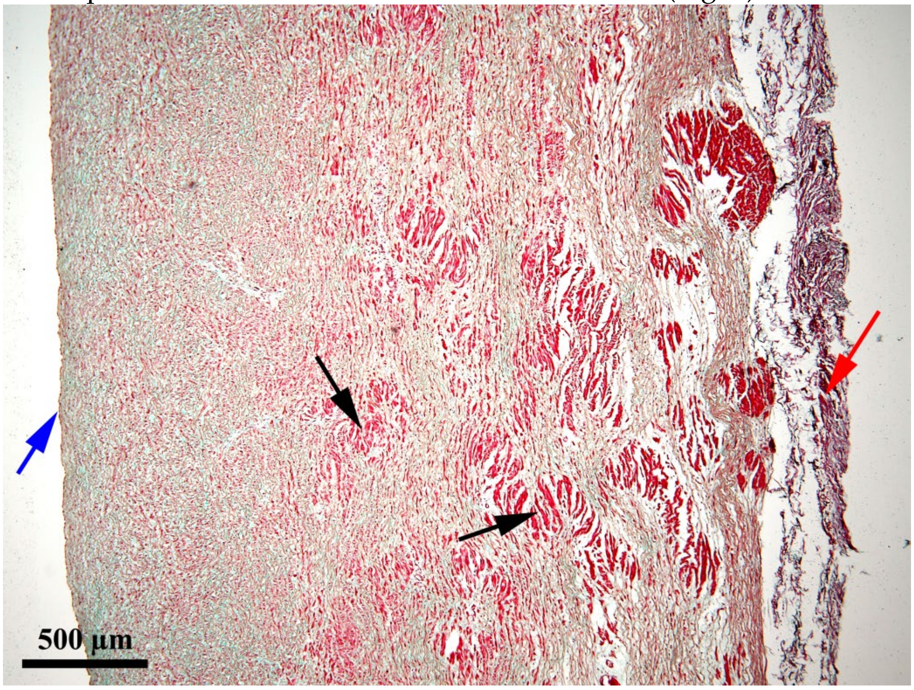

Figure 1. Ascending aorta of the domestic goat (ob. 4X)

Black arrow: muscle islands in tunica media; red arrow – tunica adventitia; blue arrow - tunica intima

The situation is largely the same in the middle of the aortic arch, both in terms of the presence, distribution, shape, density or appearance of the muscle islands in the tunica media. (Fig. 2).

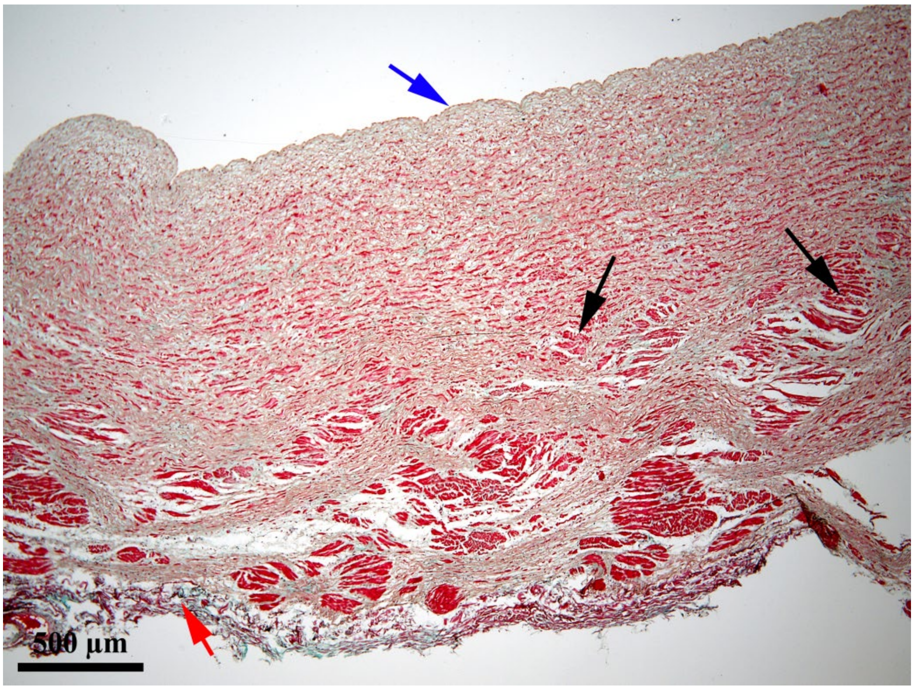

Fig. 2 Aortic arch (ob 4X)

Black arrow: muscle islands in tunica media; red arrow – tunica adventitia; blue arrow - tunica intima

In the descending thoracic aorta, the situation is similar to that existing at the level of the aortic arch, which is otherwise continued by this arterial segment. Muscle islands are numerous, with the most and larger islands being found in the outer third of the media versus the middle where the islands are somewhat scarce and the muscle cells less dense (Fig. 3).

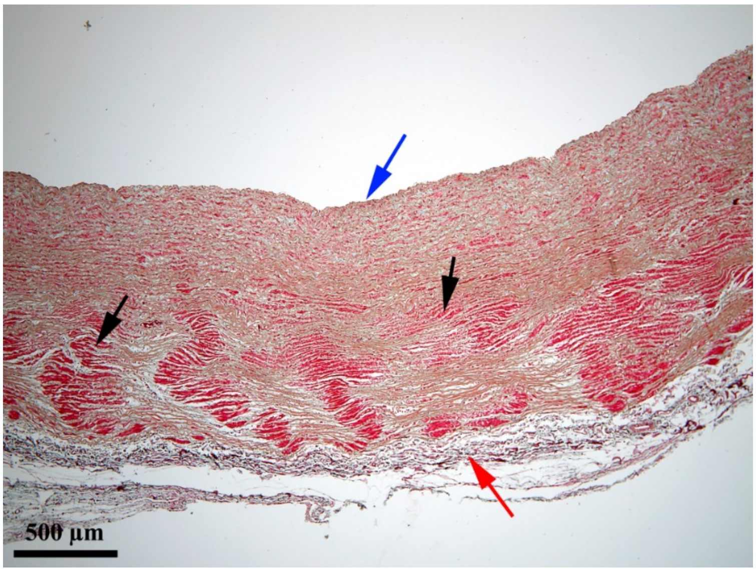

Fig. 3 Descending aorta – thoracic segment 221 (ob 4X)

Black arrow: muscle islands in tunica media; red arrow – tunica adventitia; blue arrow - tunica intima

The situation changes radically at the level of the descending abdominal aorta where muscle islands are no longer found as in the previous segments, but the general appearance is that of a typical elastic artery in which the main component is the elastic one represented by relatively rigorously arranged wavy elastic lamellae and between them cells muscle and collagen fibers. It should be noted that the adventitia of the descending abdominal aorta is thicker than that at the level of the ascending aorta, the aortic arch and the descending thoracic aorta (Fig. 4).

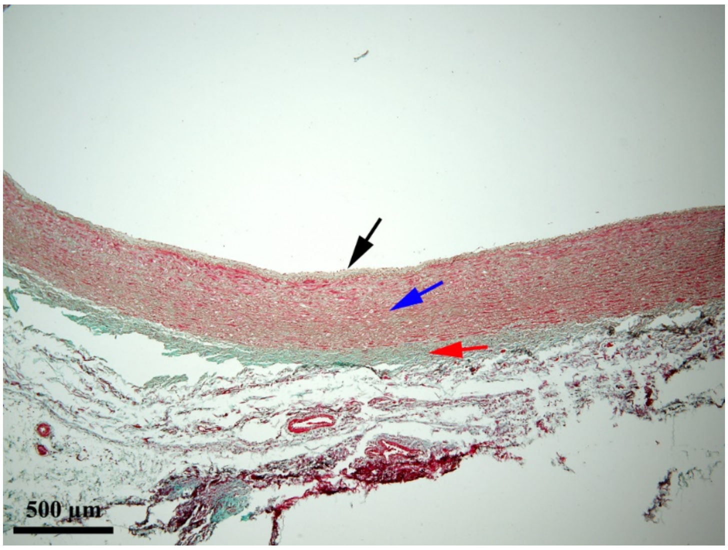

Fig. 4 Descending aorta – abdominal segment 345 (ob. 4)

Black arrow: tunica intima; blue arrow - tunica intima; red arrow – tunica adventitia

4. Discussion

In our study, we found the presence of polymorphic muscle islands in the middle of the ascending aorta, aortic arch, and descending thoracic aorta, but not in the descending abdominal aorta. These muscular islands zonally interrupt the concentric elastic lamellae characteristic of elastic arteries. In terms of number and location, the muscle islands were the most and largest in the ascending aorta, for their number and size to decrease progressively so that at the level of the abdominal aorta they disappeared completely. As an extension they are present in the outer 2/3 of the media in the ascending aorta and in the outer half in the case of the aortic arch and the descending thoracic aorta. Muscle islands present in the external half of the media were also identified by [10] in ascending aorta, aortic arch and goat thoracic aorta up to T9. From T10 and T11, the islands visibly decreased in both size and arrangement, being present here only in the outer third of the media. At the level of the abdominal descending aorta, the muscle islands were no longer found. The presence of muscle islands only in the proximal segments of the aorta suggests that they are related to the blood pressure aspects of each segment. At least two functions have been attributed to these muscle islands: strengthening the aortic wall and supplementing the windkessel function [8,9].

A gradual decrease was also noted in the case of elastic lamellae, an aspect that seems to be directly related to the stress given by blood pressure [11,12]. Blood propelled from the heart exerts the greatest tension on the ascending aorta, then the aortic arch and the proximal portion of the thoracic descending aorta. The structure of the walls of these aortic segments provides an elastic recoil that causes blood flow to become continuous and under significantly reduced pressure in the abdominal descending aorta [11]. In this context, the descending abdominal aorta has a lower number of elastic lamellae than the cranial segments, an aspect that has also been reported in humans [13]. Due to this similarity, we believe that among the goat aortic segments, the only one that lends itself as a model for studying aortic diseases in humans is the abdominal descending aorta. Being adapted to lower blood pressure than the cranial aortic segments, the goat abdominal descending aorta is structurally weaker than the thoracic aorta. This aspect appears to make it more vulnerable (prone) to atherosclerosis and aneurysm formation compared to the thoracic lineage [10, 14]. But there are also conditions such as penetrating atherosclerotic ulcers, which occur more frequently in the thoracic than in the abdominal lineage [15,16].

The muscle islands in the wall of the aortic segments are formed by smooth muscle cells interconnected with connective tissue and are preferentially vascularized by vasa vasorum and innervated by nervi vasorum. During ventricular systole, the blood is forced as a jet into the aorta, the elastic lamellae stretch and due to the fact that they are interconnected with the muscle cells, they pull the muscle islands, which also stretch to some extent. During diastole, by the rebound of the elastic lamellae, the excess blood is pushed to the next segments, and the muscle cells contract and complete the action of the elastic lamellae. These muscle islands thus represent an auxiliary pump that helps propel the blood by amplifying the elastic recoil during diastole but also ensures the increase of the mechanical resistance of the aortic wall [9]. Some authors claim that the muscle islands are probably involved in the regulation of blood flow to certain anatomical regions, more requested in a certain period. An argument in support of this statement is the fact that a similar arrangement allows for drastic circulatory changes in the posterior part of the bird's body during flight [17]. Another example is the regulation of blood flow for the brachiocephalic trunk and common carotids in the giraffe [18]. These examples suggest the continuous adaptation of animals regarding feeding and locomotion with and against gravity [1]. These examples suggest that muscle islands constitute an auxiliary pump in vessels that conduct blood in a cranial direction, while the aortic segments taken in our study conduct blood in a caudal direction. The presence of muscle islands in the wall of very well represented goat aortic segments suggests the need for an auxiliary pump to propel blood caudally. In other words, the goat needs a larger amount of blood sent to the abdominal viscera than other species of comparable size. The explanation is the fact that the goat's digestive system contains three organs in addition to monogastric animals, namely the rumen, the reticulum and the omasum. These organs, in addition to being large, are also very actively involved in the complex digestion process characteristic of ruminants. The existence of these gastric compartments makes the need for blood sent through the aorta greater in a polygastric animal than in a monogastric of comparable size. This would explain why, in the goat, the aortic media requires this additional blood propulsion pump to provide the right amount of blood and pressure to supply the viscera.

5. Conclusions

The aorta in the goat presents polymorphic muscle islands, arranged in the outer two thirds of the tunica media in the ascending aorta, the outer half at the level of the aortic arch and the descending thoracic aorta, but they are absent in the descending abdominal aorta. Their presence completes the windkessel function of the aortic wall, thus constituting an additional pump necessary to propel the blood towards the abdominal viscera, which in goats, in addition to those present in monogastrics, also contain three large and very active organs, namely the rumen, the reticulum and the omasum.

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Funding: This research received no external funding
Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Bioethics Committee of the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, nr. 403 from 29.09.2023.
Acknowledgments: In this section, you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).
Conflicts of Interest: The authors declare no conflict of interest.

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