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Morphometry of the heart orifices and morphometry and topography of the coronary ostia in the goat

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ABSTRACT

Background: The coronary vessels have been described in various species of domestic and wild ruminants. However, no studies on the detailed morphology and morphometry of heart orifices and coronary ostia in the Polish goat are available.

Materials and methods: The study was carried out on 112 female, adult dairy goats belonging to Polish Fawn Improved and Polish White Improved breed, closely related to French Alpine and Saanen, respectively.

Results: In all examined individuals, all heart orifices and heart valves were of normal structure. There was no significant diametrical difference between the aortic and pulmonary orifice. The right atrioventricular opening was significantly wider than the left atrioventricular opening. The dimension of the left coronary ostium ranged from 1.0 to 5.5 mm with the arithmetic mean (±standard deviation [SD]) of 4.3 ± 0.8 mm. The dimension of the right coronary ostium ranged from 0.5 to 5.0 mm with the arithmetic mean (±SD) of 2.8 ± 0.7 mm. Both coronary artery ostia were located under the sinotubular junction. 39/112 examined goats (34.8%) had variations in the structure of the coronary ostia such as the lack of main trunk or the presence of additional coronary ostia. They were observed in one (in 34/39 goats) or both coronary arteries (5/39 goats).

Conclusions: In goats, the dimensions of aortic and pulmonary orifices are similar while the right atrioventricular opening outsizes the left one. On the other hand, the left coronary ostium is wider than the right one. Morphological variations in the coronary ostia occur in approximately one third of goats, more often in the right than in the left ostium.
Key words: aortic orifice, pulmonary orifice, left atrioventricular ostium, right atrioventricular ostium, coronary ostia, heart, goat

INTRODUCTION

Heart vascularization is a common topic of anatomical studies both in human and veterinary medicine [5, 8, 19, 21, 35, 40, 41, 42, 43, 50, 58]. A detailed analysis of the coronary vessels has been performed in domestic and wild ruminants including goats [10], sheep [12, 40], roe deer [20], and European bison [9, 29]. Proper myocardial perfusion is, however, related not only to the architecture of the branches of the main vascular trunks but also to the topography, morphology, and dimensions of the coronary ostia [28].

In human medicine, the assessment of the morphology of heart valves and their anatomical elements, including coronary vessels, is an element of diagnostic process of various diseases and preparation for surgical procedures — coronary angiography, catheterization, and angioplasty [24, 32, 44, 52]. In veterinary medicine, it is performed mostly in animals species which serve as an experimental model for humans in biomedical research in the field of comparative anatomy of the cardiovascular system [6, 7, 13, 16, 17, 18, 33, 46, 53, 54, 51]. One of such species is the goat [48, 59]. The available studies lack detailed morphological and morphometric descriptions of the heart valves and the coronary ostia in the domestic goat.

The aim of this study was to determine the dimensions of the heart orifice and coronary ostia and assess their location in aortic sinuses in goats.

MATERIALS AND METHODS

The study was carried out on 112 female, adult dairy goats belonging to Polish Fawn Improved and Polish White Improved breed. These breeds are closely related to French Alpine and Saanen, respectively.

The hearts were collected by the veterinarians (the authors of this manuscript) during diagnostic autopsies carried out immediately after euthanasia. The goats were euthanized due to severe and irreversible clinical signs of caprine arthritis-encephalitis, mainly carpal

arthritis. According to Polish law, tests on tissues obtained post-mortem do not require the approval of the Ethics Committee (regulation of the Parliament of the Republic of Poland) [39]. The terminology used in the manuscript was based on the prevailing veterinary nomenclature [36].

Morphologic and morphometric studies

The hearts were rinsed and placed in a hypertonic 0.9% saline solution to remove blood. Next, the pericardial sac was removed and the main vessels were cut out. The hearts were weighed on a laboratory scale (AXIS AD2000, Poland) and examined for signs of hypertrophy of the walls and interventricular septum, possible thickening or fibrosis of the mitral or pulmonary valves, endocardium and myocardium.

In the first stage, morphometry of aortic orifice, pulmonary trunk orifice, left atrioventricular opening, and right atrioventricular opening was performed using Hegar dilators (SPE-MED, Poland) and valve sizers (Trifecta™ Valve Series Sizer Set, Abbot, USA). Measurements were taken with the precision of 1 mm.

The ascending aorta was cut above the aortic valve commissures. Afterwards, a longitudinal section was made between the aortic valve leaflets to visualize the left coronary ostium and the right coronary ostium. The sinotubular junction was used to determine the location of the ostia in the respective aortic sinuses of the semilunar leaflets (Fig. 1). Then, morphometry of the left coronary artery ostium and right coronary artery ostium was performed with the use of Hegar dilators (SPE-MED, Poland). Measurements were taken with the precision of 0.5 mm.

Coronary ostia were visually inspected for the following morphological variations: additional coronary ostium or ostia in the area of the coronary ostium or outside the area of the coronary artery.

Statistical analysis

Categorical variables were expressed as counts and percentages. The 95% confidence intervals (CI 95%) for proportions were calculated using Wilson's score method and the difference in proportions along with CI 95% was calculated using Newcombe's method [2]. Numerical variables were presented as the arithmetic mean, standard deviation (SD), and range. The dimensions of the ostia were compared using the paired-sample t-test (contralateral ostia) or the unpaired-sample t-test (unpaired groups). The homogeneity of variances was confirmed by an insignificant Brown-Forsythe test. The magnitude of the differences was

expressed with the mean difference with CI 95%. The correlation between the diameters of the ostia and the heart's weight was investigated using the Pearson's linear correlation coefficient (r) with CI 95% calculated according to Altman et al. [2]. Strength of correlation was classified as follows: r = 0.00 to 0.19 — very weak, 0.20 to 0.49 — weak, 0.50 to 0.69 — moderate, 0.70 to 0.89 — strong, and 0.90 to 1.00 — very strong [1]. All statistical tests were two-sided and a significance level (α) was set at 0.05. Statistical analysis was performed in TIBCO Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA).

RESULTS

The heart's weight ranged from 43 to 450 g with the arithmetic mean (±SD) of 230.5 ± 60.0 g. In all studied goats, the aortic valve consisted of the three semilunar leaflets: left, right, and septal that respectively delimited the left coronary, right coronary, and the non-coronary aortic sinuses. The diameter of the aortic orifice ranged from 10 to 23 mm with the arithmetic mean (±SD) of 16.4 ± 2.1 mm (Fig. 2a). On the wall of the aorta, the right and left coronary ostia were observed in the respective aortic sinus. In all examined individuals, the coronary ostia were located under the sinotubular junction (Fig. 1). Variations in the structure of the coronary ostia were observed in 39 / 112 goats (34.8%, CI 95%: 26.6% – 44.0%). In 34 / 39 goats (87.2%) morphological variations were observed in only one coronary artery — in 11 goats in the left and in 23 goats in the right. In the remaining 5 goats morphological variations were present in both coronary arteries. They were related to the structure of the left and right coronary ostia, or the presence of additional coronary ostia.

Morphological variations of the left coronary artery were found in 16 / 112 goats (14.3%, CI 95%: 9.0% – 22.0%) and were as follows:

— In 11 / 16 goats (68.8%), two well-defined openings (paraconal interventricular branch and the left circumflex branch) were noted in the area of the left coronary ostium. The close proximity of these structures indicated that these individuals lacked the main left trunk (Fig. 3).

— In 5 / 16 goats (31.2%), an additional coronary ostium was found outside the area of the left coronary artery. It was located in the aortic sinus of the left semilunar leaflet on the side of the intermediary aortic valve commissure or the left aortic valve commissure (Fig. 4).

Morphometric studies of the left coronary ostium were carried out in 101 / 112 goats (90.2%) in which the common left trunk was present. The dimension of the left coronary ostium ranged from 1.0 to 5.5 mm with the arithmetic mean (±SD) of 4.3 ± 0.8 mm (Fig. 2b).

The following morphological variations in the right coronary artery were observed in 28 / 112 goats (25.0%; CI 95%: 17.9% – 33.8%):

— in 20 / 28 goats (71.4%), an additional coronary ostium was noted outside the area of the right coronary artery. It was located in the aortic sinus of the right semilunar leaflet on the side of the intermediary aortic valve commissure (Fig. 5b);

— in 8 / 28 goats (28.6%), two additional coronary ostia were found outside the outline of the right coronary ostium. They were located in the aortic sinus of the right semilunar leaflet on the side of the intermediary aortic valve commissure (Fig. 5a).

The dimension of the right coronary ostium ranged from 0.5 to 5.0 mm with the arithmetic mean (±SD) of 2.8 ± 0.7 mm (Fig. 2b). The morphological variations were significantly more common in the right than the left coronary ostium (difference in proportion of 10.7%, CI 95%: 0.4% – 20.8%).

The pulmonary valve consisted of the three semilunar leaflets: left, right, and intermediate. The dimension of the pulmonary orifice ranged from 11 to 27 mm with the arithmetic mean (±SD) of 16.7 ± 2.9 mm (Fig. 2a).

The bicuspid valve was composed of the parietal and septal cusp. The dimension of the left atrioventricular opening ranged from 14 to 35 mm with the arithmetic mean (±SD) of 25.9 ± 3.0 mm (Fig. 2a).

The tricuspid valve consisted of three cusps: parietal, septal and angular. The dimension of the right atrioventricular opening ranged from 15 to 39 mm with the arithmetic mean (±SD) of 29.7 ± 3.5 mm (Fig. 2a).

There was no significant difference in the dimension between the aortic and pulmonary orifice (the mean difference of -0.2 mm, CI 95%: -0.7 – 0.2 mm; $p=0.303$). The right atrioventricular opening was significantly wider than the left atrioventricular opening (the mean difference of 3.8 mm, CI 95%: 3.3 – 4.3 mm; $p<0.001$) (Fig. 2a) and the left coronary ostium was significantly wider than the right coronary ostium (the mean difference of 1.5 mm, CI 95%: 1.3 – 1.6 mm; $p<0.001$) (Fig. 2b).

All the heart dimensions were significantly positively correlated with the heart weight ($p<0.001$). The correlation was moderate in the case of the left atrioventricular opening ($r=0.60$, CI 95%: 0.47 – 0.71) and the right atrioventricular opening ($r=0.57$, CI 95%: 0.43 – 0.68) and weak in the case of the pulmonary orifice ($r=0.48$, CI 95%: 0.32 – 0.61), aortic orifice ($r=0.38$, CI 95%: 0.21 – 0.53) as well as the left ($r=0.41$, CI 95%: 0.23 – 0.56), and right coronary ostium ($r=0.31$, CI 95%: 0.13 – 0.47).

There was no significant difference between the dimension of the right coronary ostium in goat in which the right additional ostium was absent (n=84; 2.8 ± 0.7 mm, range 0.5 – 5.0 mm) or present (n=28; 2.9 ± 0.6 mm, range 2.0 – 4.5 mm) (p=0.469). Neither was there any significant difference between the dimension of the left coronary ostium in goat in which the left accessory ostium was present (n=5; 4.0 ± 0.4 mm, range 3.5 – 4.5 mm) or absent (n=96; 4.3 ± 0.8 mm, range 1.0 – 5.5 mm) (p=0.145).

Ethics approval and consent to participate

Parliament of the Republic of Poland: Ustawa z dnia 15 stycznia 2015 r. o ochronie zwierząt wykorzystywanych do celów naukowych lub edukacyjnych. Dz.U. 2015 r. poz. 266. www.dziennikustaw.gov.pl/du/2015/266/D2015000026601.pdf

DISCUSSION

Publications in the field of human medicine present detailed results of morphometry of the heart orifices, leaflets of the heart valves, and the diameter of the ostia and trunks of the coronary arteries. Based on these studies, surgeries are performed to replace entire valves or their parts, as well as diagnostic and repair procedures on the coronary arteries [4, 14, 15, 26, 30, 31, 32, 37, 45, 49, 56]. A substantial development in veterinary cardiology has taken place in recent years. However, only a few morphometric studies on animal hearts have been published. These include European bison [9], cat [6, 7], cattle [22, 23], chicken [11], hamster [13, 17, 18], donkey [38], and dog [3]. This is particularly important in the case of species that are used as biomedical models [55]. The similarity in the size of organs between goats and humans has caused an increase in the usage of these animals; instead of dogs, as a model in cardiological studies. Moreover, societal expectations, emotional connections, and growing costs, have contributed to this [27, 57].

In all examined goats, the coronary arteries were located in the area of the aortic sinus of the semilunar leaflet, left and right, respectively, just below the sinotubular junction. A similar situation was noted in the European bison [9]. For both ruminant species, the sinotubular junction is a well-defined structure. It protrudes towards the lumen of the aorta, which determines the location of the coronary ostia [9]. Therefore, the method proposed by Loukas et al. [30] was used.

To determine the location of the coronary ostia, the authors also use the intercommissural line, which allows for the specification of three types of location – on the intercommissural line, below the intercommissural line, and above the intercommissural line. The method proposed by Cavalcanti et al. [15] is widely used in human and veterinary

medicine [6, 15, 40, 41]. According to this method, it was frequently found that in humans, both coronary ostia were below the intercommissural lines (42% for the left coronary artery, 60% for the right coronary artery). The location of the ostia on the intercommissural lines was observed the least frequently: 18% for the left coronary artery and 12% for the right coronary artery [15].

Observations by Islam et al. [22] also showed differences in the location of the coronary ostia. The authors emphasized that the right coronary ostium in the bovine heart was located above the intercommissural line.

Studies on the location of the coronary ostia were also carried out in domestic cats. Most often, both coronary ostia were located on the intercommissural line – in the case of the left coronary artery in 42 cats (65%), and the case of the right coronary artery in 43 cats (66%). Least often, coronary ostia were located above the intercommissural lines – in 6 subjects (9%) for the left coronary artery and 9 (14%) for the right coronary artery [6].

In various animal species, the authors conducted morphological observations regarding the symmetry of the location of the coronary ostia. Pereira et al. [40, 41] described the symmetrical position of the coronary ostia in 45 out of 70 horses, 42 out of 58 sheep, and 16 out of 60 pigs. In the case of the domestic cat, a similar situation was described in 50 out of 65 cats studied [6].

Morphometric observations of the coronary ostia were carried out in subjects with no variations in the structure of the main ostium. In all examined goats, the left coronary artery ostium was larger – the arithmetic mean (±SD) of 4.3 ± 0.8 mm than the right one – the arithmetic mean (±SD) of 2.8 ± 0.7 mm. Similar morphometric ratios were obtained in European bison, in which the left coronary ostium was significantly larger than the right coronary ostium. It was longer by 4.5 mm, and wider by 1.6 mm. Its area was on average 31.6 mm^2 larger than the right coronary ostium [9]. In the case of the Bactrian camel, the mean diameter of the left coronary artery was 16.98 mm and the right one was 11.08 mm [58]. Research by Ozgel et al. [38] in donkeys also showed that the diameter of the left coronary artery (0.9-1.0 mm) was larger than the diameter of the right coronary artery (0.1-0.3 mm).

In the crab-eating macaquee the diameters of the left and right coronary artery were 1.2-2.5 mm (mean 1.8 mm) and 0.7-1.2 mm (mean 0.9 mm), respectively [54]. Similar results were obtained in the green monkey and crab-eating macaque by Nikolic et al. [34] – the average diameter of the left coronary artery was 1.65±0.39, and that of the right one 0.94±0.15 mm.

In the case of the domestic cat, the surface area of the main coronary ostia was measured. In all subjects, the surface area of the left coronary artery (0.54-2.64 mm^2) was greater than the area of the right coronary artery (0.12-1.37 mm^2) [7].

Similar morphometric relationships have been described in human medicine for the coronary ostia. In most of the examined hearts, the ostium of the left coronary artery was larger than the ostium of the right one. This is confirmed by the results obtained by Cavalcanti et al. [15], Kaur et al. [25], Sirikonda and Sreelatha [47].

One third of goats examined in our study had variations related to the structure of the left or right coronary ostia or the presence of additional coronary ostia. Variations were usually observed in only one coronary artery. In veterinary medicine, few publications have described the occurrence of variants of the coronary ostia and additional ones. In the research conducted on the European bison, the morphological varieties of the coronary ostia or the presence of additional coronary ostia were described in 18 out of 27 examined bison (67%). Both in goats and European bison, they more often affected the right coronary artery [9]. In the case of the right coronary artery, similarly to the European bison, the presence of an additional coronary ostia close to the intermediary aortic valve commissure was most often observed. Observations by Pereira et al. [40, 41] showed the presence of additional coronary ostia in 8.6% of horses, 18.6% of sheep [40], and 10% of swine [41]. Studies were also carried out on carnivores. Of the 65 domestic cats examined, 13 (20%) had variations related to the morphology of the coronary ostia or the presence of additional coronary ostia. They were observed both in the left and right coronary arteries [6]. The presence of additional coronary ostia was also found in more than 5% of Syrian hamsters tested [13, 17, 18]. Studies conducted on the vascularization of the heart of green monkeys and crab-eating macaques showed the presence of the third coronary artery – TCA [34].

In 10% examined goats, two independent ostia (left circumflex branch and interventricular paraconal branch) were observed instead of the main trunk of the left coronary artery. A similar variation was noted in 5 out of 27 European bison examined (19%) [9]. It was much less frequently reported in carnivores – in 1 out of 20 examined dogs (5%) [35] and 2 out of 65 cats (3%) [6].

It is noteworthy that diseases associated with disorders of the heart's vessels in animals have not been studied in detail. In many cases, it is difficult to assess whether the varied number of coronary vessels can be treated as the independence of larger branches of the main arteries. It should be assumed that their effect on the vascularization of the heart depends on

the depth of the variety, i.e. whether it involves the ostium itself or the further course of the vessel.

The analysis of anatomical variations can contribute to obtaining an actual image of the inside of the human and animal body, which is crucial in everyday clinical practice. Deviations from the most common arrangement of specific anatomical structures are common and constitute the actual norm [60].

CONCLUSIONS

The dimensions of aortic and pulmonary orifices are similar while the right atrioventricular opening outsizes the left one. On the other hand, the left coronary ostium is wider than the right one. Morphological variations in the coronary ostia in goats are common and occur in approximately one third of goats, more often in the right than in the left ostium.

Conflict of interest: None declared

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Figure 1. Location of the coronary ostia. The sinotubular junction (dotted lines). 1 — the left semilunar leaflet; 2 — the right semilunar leaflet; 3 — the septal semilunar leaflet; 4 — the left aortic valve commissure; 5 — the intermediary aortic valve commissure; 6 — the right aortic valve commissure; 7 — the left coronary ostium; 8 — the right coronary ostium. Scale bar 2 mm.

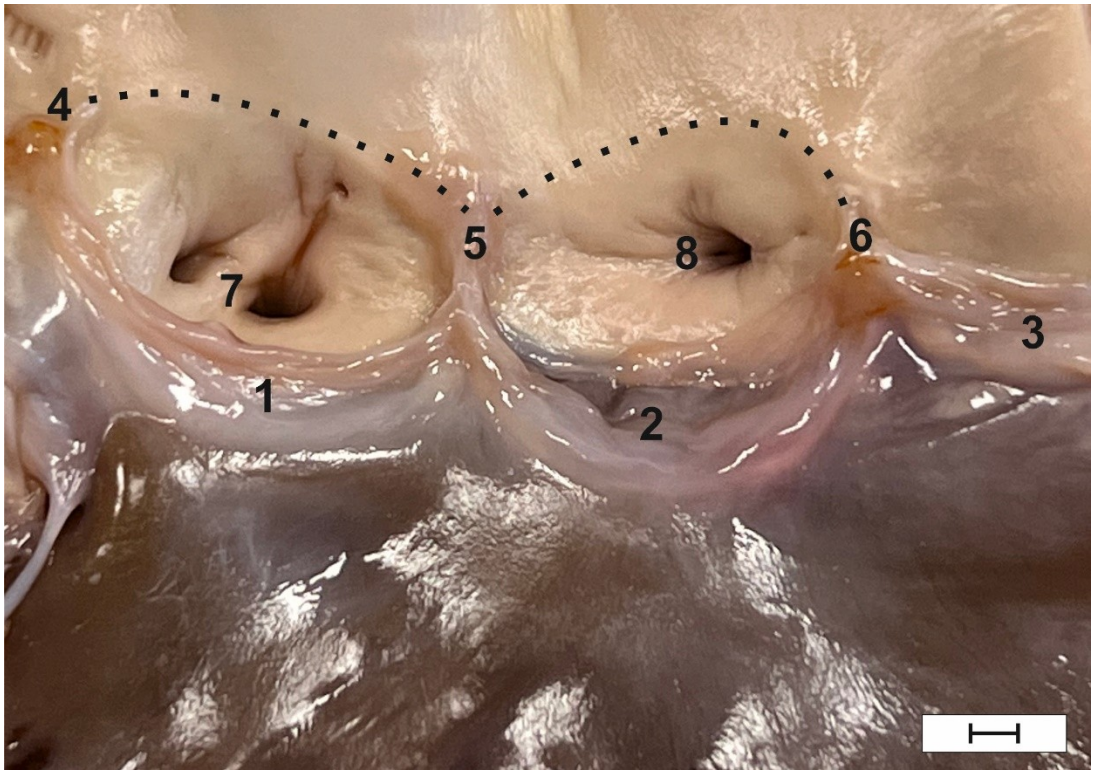

Figure 2. Measurements: **A.** Of heart orifice; **B.** Of coronary ostia.

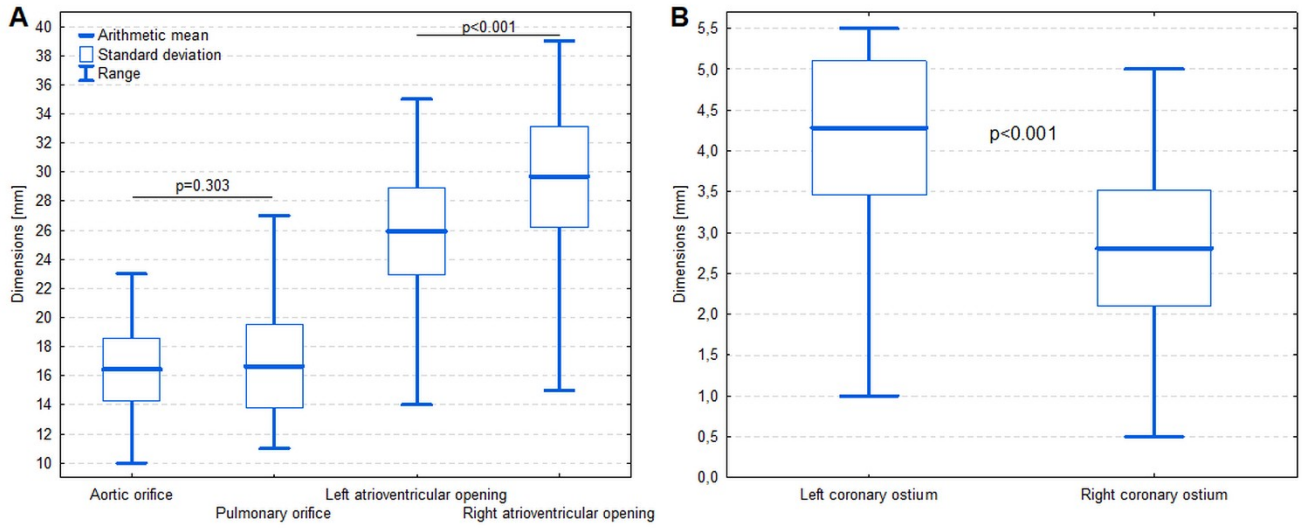

Figure 3. Overview of the aortic valve. 1 — the septal semilunar leaflet, 2 — the left semilunar leaflet, 3 — the right semilunar leaflet, 4 — the right aortic valve commissure, 5 — the left aortic valve commissure, 6 — the intermediary aortic valve commissure, 7 — lack of the main trunk of the left coronary artery, 8 — the right coronary ostium. Scale bar 3 mm.

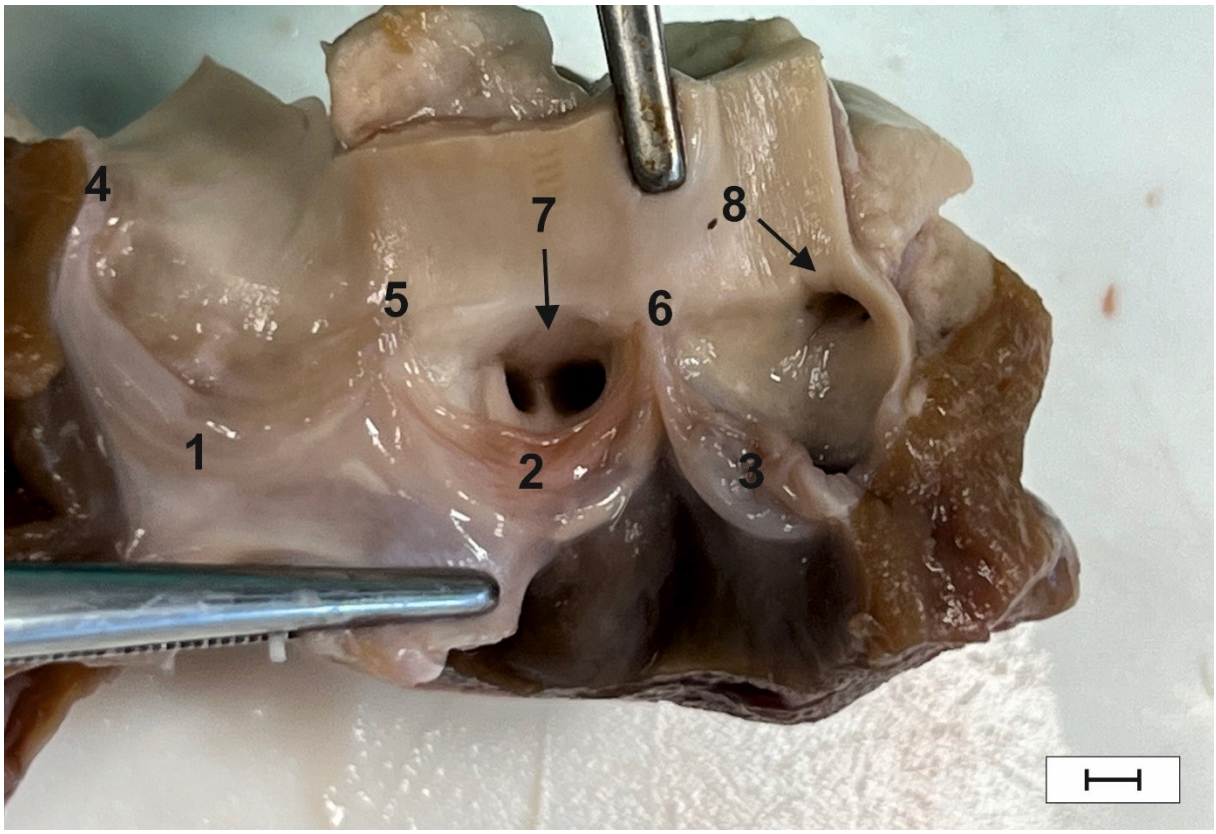

Figure 4. Overview of the aortic valve A, B — the additional coronary ostia in the left aortic sinus. 1 — the left semilunar leaflet; 2 — the right semilunar leaflet; 3 — the septal semilunar leaflet; 4 — left aortic valve commissure; 5 — the intermediary aortic valve commissure; 6 — right aortic valve commissure; 7 — the right coronary ostium; 8 — the left coronary ostium; 9 — the additional coronary ostium. Scale bar 3 mm.

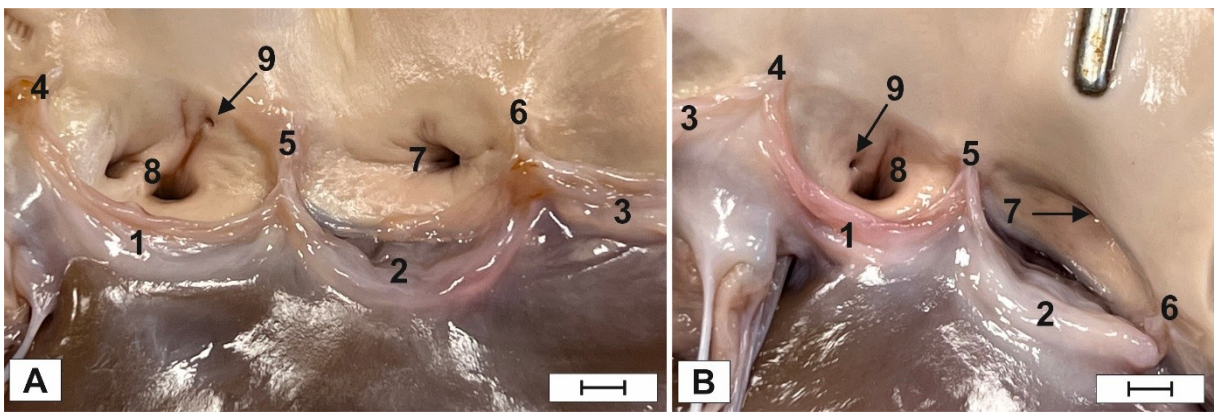

Figure 5. Overview of the aortic valve A, B — the additional coronary ostia in the right aortic sinus. 1 — the septal semilunar leaflet; 2 — the right semilunar leaflet; 3 — the left semilunar leaflet; 4 — left aortic valve commissure; 5 — the intermediary aortic valve commissure; 6 — right aortic valve commissure; 7 — the right coronary ostium; 8 — the additional coronary ostium. Scale bar 3 mm.