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ISSN: 0015-5659

e-ISSN: 1644-3284

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DOI: 10.5603/FM.a2019.0041

Article type: ORIGINAL ARTICLES

Submitted: 2019-01-31

Accepted: 2019-03-13

Published online: 2019-04-05

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Articles in "Folia Morphologica" are listed in PubMed.

Morphometry and topography of the coronary ostia in the European bison

Running head: The coronary ostia in the European bison

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Abstract

Background: Coronary vessels have been widely studied in many species of domestic and wild mammals. However, there are no available literature reports describing the morphology and morphometry of the coronary ostia of the European bison (*Bison bonasus*). The aim of this study was to measure the area of the coronary ostia and assess their localization in the coronary sinuses of the aortic root in the European bison.

Material and methods: The study material comprised 27 hearts from European bison of both sexes (16 males and 11 females), from 3 months to 26 years old, inhabiting the Białowieża Forest (Białowieża National Park, Poland). The animals were divided into two age groups: ≤ 5 years (group I) and > 5 years (group II).

Results: In all the studied European bison, the aortic valve consisted of three semilunar leaflets, left, right and septal. The ostia of both coronary arteries were located beneath the

sinotubular junction. The dimensions of the left coronary ostium were larger than those of the right coronary ostium. They were longer by on average 4.5 mm (CI 95%: 3.5 to 5.6 mm), they were wider by on average 1.6 mm (CI 95%: 1.0 to 2.2 mm) and they had a larger area by on average 31.6 mm² (CI 95%: 22.7 to 40.5 mm²). This was evident both in young and in adult bison. After adjusting for age, there were no differences in the ostia dimensions between males and females. There were no differences in the structure of the left and right coronary arteries in nine animals. In the remaining 18 animals, there were variations in the morphology of the coronary ostia or additional ostia.

Conclusions: Because of the anatomical similarity between the European bison and other ruminants, the results of this study can be applied to the other species including endangered ones.

Key words: coronary ostia, left coronary artery, right coronary artery, European bison, heart

Introduction

The European bison is an endangered species. Although the overall bison population has increased as a result of successful restitution programs, this species still requires protection. Numerous breeding and research programs are currently being developed. Understanding the normal and clinical anatomy of the bison plays an important role in proactive species conservation. Although there are over 100 morphological studies of individual systems and organs of the bison, few of them focus on the organs of the cardiovascular system [7, 25, 32]. Morphometric studies of selected bison heart parameters were conducted by Węgrzyn and Kupczyńska [46, 47]. However, none of the available studies provides detailed morphological and morphometric descriptions of the coronary ostia.

Coronary vessels have been studied in domestic and wild ruminants including the Angora and Akkamaran goats [10], domestic goat (*Capra hircus*) (8), the roe deer (*Capreolus capreolus*) [19], the Bactrian camel (*Camelus bactrianus*) [48], the one-humped camel (*Camelus dromedarius*) [20] and the European bison (*Bison bonasus*) [25].

This is the first study on the topography and morphometry of the coronary ostia in the European bison. Given the anatomical similarity between the European bison and other ruminants, the results of this study may be applicable to other species, including endangered ones.

The aim of this study was to measure the coronary ostia of the European bison and assess their localization in the coronary sinuses of the aortic root, as well as to contribute to the body of knowledge of comparative anatomy of wild mammals.

Material and methods

The study material comprised 27 hearts from European bison (*Bison bonasus*) of both sexes (16 males and 11 females), from 3 months to 26 years old, with a median age of 5.5 years (IQR from 1.5 to 20 years), inhabiting the Białowieża Forest (Białowieża National Park, Poland). The age did not differ significantly between sexes ($p=0.080$). The animals were divided into two age groups: ≤ 5 years (group I) and >5 years (group II). The information on the age of the animals was drawn from the Białowieża Nature Reserve Record Book.

The weight of each animal was determined under field conditions following legal culls. The Białowieża National Park was responsible for the culling of the European bison. The animals were not killed for the purpose of this study. Population control, bone fractures and car accidents were the most common reasons for culling the animals. The culling was carried out with the permission of the Ministry of Environment and the General Director for Environmental Protection in Poland (decision number: DOP-OZGIZ. 6401.06.7.2012.ls, DOP-OZ.6401.06.7.2012.ls.1 and DLP-III-4102-459/36490/14/ZK).

The hearts and other organs were collected by the authors (veterinary doctors) during dissection. A pathological examination of the whole body was performed prior to the heart dissection. The hearts were investigated for signs of hypertrophy, possible thickening or fibrosis of the mitral or pulmonary valve, endocardium and myocardium. The necropsy protocols are available in the Białowieża National Park. According to the Polish law, tests on tissues obtained *post-mortem* do not require an approval of the Ethics Committee (Parliament of the Republic of Poland, 2015) [34].

The morphologic and morphometric assessments were carried out using ECLERIS (HALOLUX 150) and GLOBAL (MW 725F-I) surgical microscopes. Both devices had integrated video channels and image analysis software (AxioVision Rel. 4.7, Carl Zeiss MicroImaging GmbH, Jena, Germany).

The terminology used in the manuscript is in accordance with the prevailing veterinary nomenclature (Nomina Anatomica Veterinaria 2017) [31].

Morphologic and morphometric studies

After being harvested, the hearts were washed under running-water and placed in a hypertonic NaCl solution to remove blood. Then the pericardial sac was removed, and the ascending aorta was cut above the aortic valve commissures. Next, a longitudinal cut between the aortic valve leaflets was made to visualize the left coronary ostium and the right coronary ostium.

The localization of the coronary ostia within the respective aortic sinuses was determined in relation to the sinotubular junction (Fig. 1) [26]. Then the morphometry of the ostia of the left and right coronary artery was performed. The width (the shortest dimension) and the length (the longest dimension) of each ostium were determined (Fig. 1). The ostium area was calculated using the formula for an ellipse area: $\text{Area} = \pi \times a \times b$, where a and b are the length of the semi-major axis and the semi-minor axis respectively, and $\pi \approx 3.14$.

Statistical analysis

The ostium dimensions were presented as the arithmetic mean and standard deviation (SD), while age was presented as the median and interquartile range (IQR) due to non-normal distribution according to the Shapiro-Wilk W test ($p=0.002$). The range was always reported. The age of males and females was compared using the Mann-Whitney U test. The left and the right coronary ostium dimensions were compared using the paired Student's t-test and the mean difference was provided with a 95% confidence interval (CI 95%). The ostium dimensions of males and females were compared after adjusting for age using the analysis of covariance (ANCOVA). A two-sided significance level (α) was set at 0.05. The statistical analysis was performed using the Statistica 12 software (StatSoft, Inc.).

Results

In all the studied European bison, the aortic valve consisted of the three semilunar leaflets: the left, the right and the septal leaflet (*valvula semilunaris sinistra, dextra et septalis*) that demarcated the left coronary, right coronary and septal (non-coronary) aortic sinuses (*sinus aortae valvulae semilunaris sinistra, dextra and septalis*), respectively. Three commissures were noted, which included the right aortic valve commissure (*commissura valvae aortae dextra*) between the right and septal leaflet, the left aortic valve commissure (*commissura valvae aortae sinistra*) between the septal and left leaflet, and the intermediary aortic valve commissure (*commissura valvae aortae intermedia*) between the left and the right leaflets (Fig. 1).

In all the examined animals, the coronary ostia were located beneath the sinotubular junction (Fig.1).

The left coronary ostium was significantly larger than the right coronary ostium. It was longer by 4.5 mm (CI 95%: 3.5 to 5.6 mm), wider by 1.6 mm (CI 95%: 1.0 to 2.2 mm). Its area was on average 31.6 mm² (CI 95%: 22.7 to 40.5 mm²) larger than the right coronary ostium. This was evident both in the young and adult bison (Table 1). After adjusting for age, there were no ostium differences in the ostium dimensions between males and females.

There were no anatomical deviations in the coronary ostia in nine (33%) out of the 27 examined animals. In the remaining 18 (67%) animals, there were variations associated with the morphology of the left and right coronary ostium or the presence of additional coronary ostia. In 16 bison, those variations affected one coronary artery. In the remaining two individuals, the anatomical deviations were present in both coronary arteries (Fig. 2,3).

Left coronary artery

There were no changes in the left coronary artery in 20 animals. The following morphological variations were observed in seven bison:

- The ostium of the additional coronary vessel was located outside the area of the left coronary ostium. It was located in the left coronary sinus close to the intermediary aortic valve commissure (Fig. 2A).
- In 5 bison, two well developed ostia were present in the left coronary sinus. The proximity of these ostia indicated that those animals lacked a left main trunk. At that site, the vessel divided into the paraconal interventricular branch and the left circumflex branch (Fig. 2B).

Right coronary artery

There were no changes in the right coronary artery in 14 animals. In 13 bison, the following morphological differences were observed:

- In 11 subjects, an additional coronary ostium was found. It was located outside the area of the right coronary ostium close to the intermediary aortic valve commissure (Fig. 3B).
- In one bison, there was an additional coronary ostium located in the right coronary sinus under the main ostium and close to the right aortic valve commissure (Fig. 3A).
- One animal had two additional coronary ostia outside the area of the right coronary ostium. They were located in the right coronary sinus and above the ostium of the right coronary artery (Fig. 3C).

Discussion

There are numerous studies assessing cardiac vascularization in domestic and wild animals. These include studies of the dog (*Canis lupus f. familiaris*) [6, 30], cat (*Felis silvestris f. catus*) [2-4], white rhinoceros (*Ceratotherium simum*) [18], ringed seal (*Pusa hispida*) [40], South American fur seal (*Arctocephalus australis*) [35] and night monkey (*Aotus* sp.) [36]. Some studies were also performed on domestic and wild ruminants.

However, there are few studies in veterinary medicine describing a detailed morphology and morphometry of the aortic valve and coronary ostia. Currently available studies described those structures in the cat [4, 5], cattle (*Bos taurus*) [22], chicken (*Gallus gallus f. domestica*) [9], Syrian hamster (*Mesocricetus auratus*), [12, 16, 17] and donkey (*Equus asinus*) [33]. The majority of those studies were performed on experimental animal models that shared anatomical similarities with the human heart [4, 5, 12, 15, 16, 17, 28, 38, 43, 44].

Numerous similar studies have been carried out on humans. They describe in great detail the morphometry of the aortic valve leaflets, the diameter of the ostia and the main trunk of both coronary arteries, the distance of the ostia from the commissures and the nadirs of the aortic sinus. Aortic valve replacement or repair and coronary artery bypass grafting are based on those measurements [1, 11, 13, 14, 23, 24, 26, 27, 37, 39, 41, 42, 45].

The coronary ostia of the studied bison were located in the area of the left and the right coronary sinuses, immediately below the semitubular junction. This structure is well expressed in the bison and protrudes into the aortic lumen, which determines the location of the coronary ostia. Hence, the method proposed by Loukas et al. [26] was used to describe the location of the ostia. In humans, the intercommissural line is used to identify three locations of the ostia [14]. It is drawn between neighbouring commissures of the aortic valve leaflets at the site of their attachment to the aortic wall. That method enabled the authors to distinguish three types of ostia: those located on, beneath and above the intercommissural line. In the cited study in humans, the authors found that the ostia were most commonly located below the intercommissural line. That was true for 42% of the left coronary ostia and 60% of the right coronary ostia. Forty percent of left coronary ostia and 28% of the right coronary ostia were located above the intercommissural line. Only 18% of the left coronary ostia and 12% of the right coronary ostia were located on the intercommissural line. The aforementioned authors did not describe the presence of the sinotubular junction.

The intercommissural line was used to describe the location of the coronary ostia in 65 cats. There were no significant differences in the location of the coronary ostia between male

and female cats. In most individuals, the coronary ostia were located on the intercommisural line. The left coronary ostia were present at this location in 42 cats (65%), and the right coronary ostia were located at this line in 43 cats (66%). Seventeen left coronary ostia (26%) and 13 right coronary ostia (20%) were located below the intercommisural line. The fewest ostia were located below the intercommisural line, which included six left coronary ostia (9%) and nine right coronary ostia (14%) [4].

In the studied bison, all ostium dimensions of the left coronary artery were significantly larger than those of the right coronary artery. The left coronary ostium was longer by 4.5 mm (CI 95%: 3.5 to 5.6 mm), wider by 1.6 mm (CI 95%: 1.0 to 2.2 mm) and had an area larger by on average 31.6 mm² (CI 95%: 22.7 to 40.5 mm²) than the right coronary ostium. That was evident both in the young and in the adult bison. After adjusting for age, there were no ostium differences between the studied males and females.

The study carried out in the green monkey (*Cercopithecus aethiops*) and crab-eating macaque (*Macaca fascicularis*) showed that the mean diameter of the left coronary artery was 1.65±0.39, and the mean diameter of the right coronary was 0.94±0.15 mm [29]. However, according to Teofilovski-Parapid et al. the diameter of the left coronary artery ranged from 1.2–2.5 mm (mean 1.8 mm), and the right coronary artery ranged from 0.7–1.2 mm (mean 0.9 mm) in the crab-eating macaque [44]. Meanwhile, observations by Ozgel et al. showed that the diameter of the left coronary artery was larger (0.9–1.0) mm than that of the right coronary artery (0.1–0.3 mm) in studied donkeys [33]. According to Barszcz et al. [5], the surface area of the left coronary ostium (0.54–2.64 mm²) was larger than that of the right coronary ostium (0.12–1.37 mm²) in all the studied domestic cats. The mean difference between the surface areas was 0.65 mm². The statistical analysis carried out using the NIR test did not reveal significant differences between the studied population of male and female cats [5].

Currently available studies described the mean value of the diameter of the coronary ostia in humans. Observations by Sirikonda and Sreelatha [39] showed that the left coronary ostium was larger (4.11±0.88 mm) than the right coronary ostium (2.77±0.905 mm). However, according to Bhimalli et al. [11], the mean diameter of the left coronary artery measured 3.17±0.34 mm, while that of the right coronary artery measured 2.38±1.33 mm. Cavalcanti et al. [14] reported those values to be 4.25±0.94 mm and 3.46±0.93mm, respectively. The observations carried out by Kaur et al. [23] revealed that the diameter of both coronary arteries was the same in 9% of studied hearts, and the diameter of the right coronary ostium was larger only in 29% hearts.

We found structural variations of the coronary ostia and the presence of additional ostia in 18 of the 27 studied bison (67%). The most common variation was the presence of a single coronary ostium (left or right). One or two additional arteries were also observed, with various locations of their ostia.

The presence of additional coronary arteries in animals is rare. A study carried out on 55 green monkeys and crab-eating macaques revealed the presence of a third coronary artery – TCA [29]. It was located near the right coronary ostium in one animal. Numerous studies were carried out to assess the anatomy of the aortic valve, structural abnormalities of the coronary ostia and additional ostia in Syrian hamsters. The presence of additional coronary ostia was observed in 5% of the studied animals [12, 16, 17]. There were structural variations of the left and right coronary ostia or additional ostia present in thirteen (20%) of 65 domestic cats [4].

Five of the studied bison did not have a common left coronary artery trunk. This morphological variant was associated with an independent origin of the left circumflex branch and paraconal interventricular branch. A similar finding was reported in one (5%) of the 20 studied dogs [30] and in two (3%) of the 65 cats [4].

In humans, a larger number of coronary ostia is regarded as an independent origin of one of the coronary artery branches of the left or right coronary arteries. The influence of these variations on the circulation depends on the extent of the anatomical alteration – whether it affects the ostium alone or the course of the vessel as well [21]. In animals, coronary artery disorders have not been studied in detail.

Conclusions

In all the examined animals, the coronary ostia were located beneath the sinotubular junction. The left coronary ostium was significantly larger than the right coronary ostium. There were no anatomical deviations in the coronary ostia in nine (33%) out of the 27 examined animals. In 18 (67%) animals, there were variations associated with the morphology of the left and right coronary ostium or the presence of additional coronary ostia.

Funding: The translation of publication was paid by the Wroclaw Center of Biotechnology, 2014-2018 Leading National Research Center (KNOW) program.

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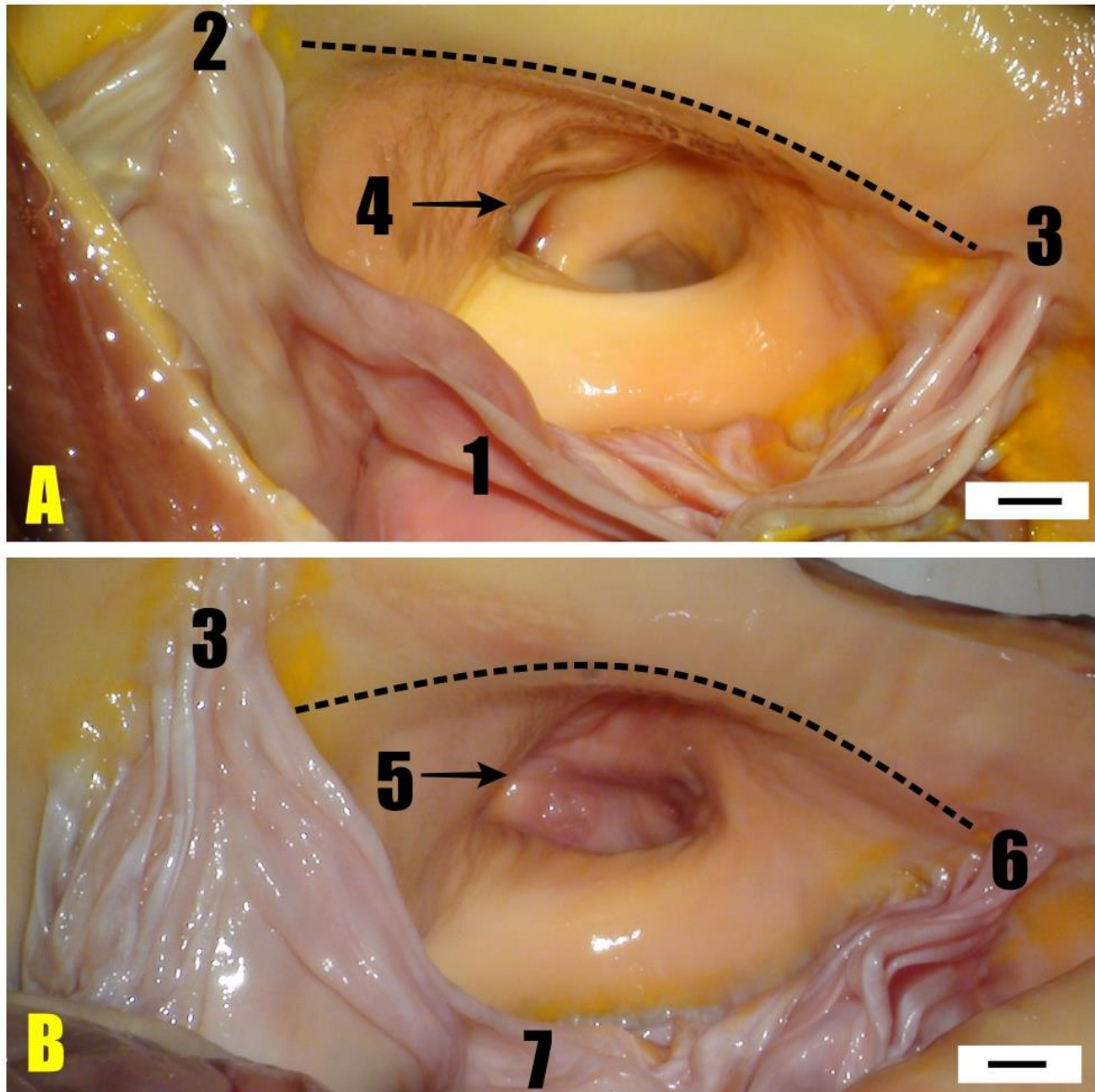


Figure 1. Location of the coronary ostia. A – the left coronary ostium, B – the right coronary ostium. The sinutubular junction (dotted lines). 1 – the left semilunar leaflet, 2 – the left aortic valve commissure, 3 – the intermediary aortic valve commissure, 4 – the left coronary ostium, 5 – the right coronary ostium, 6 – the right aortic valve commissure, 7 – the right semilunar leaflet. Scale bar 5 mm.

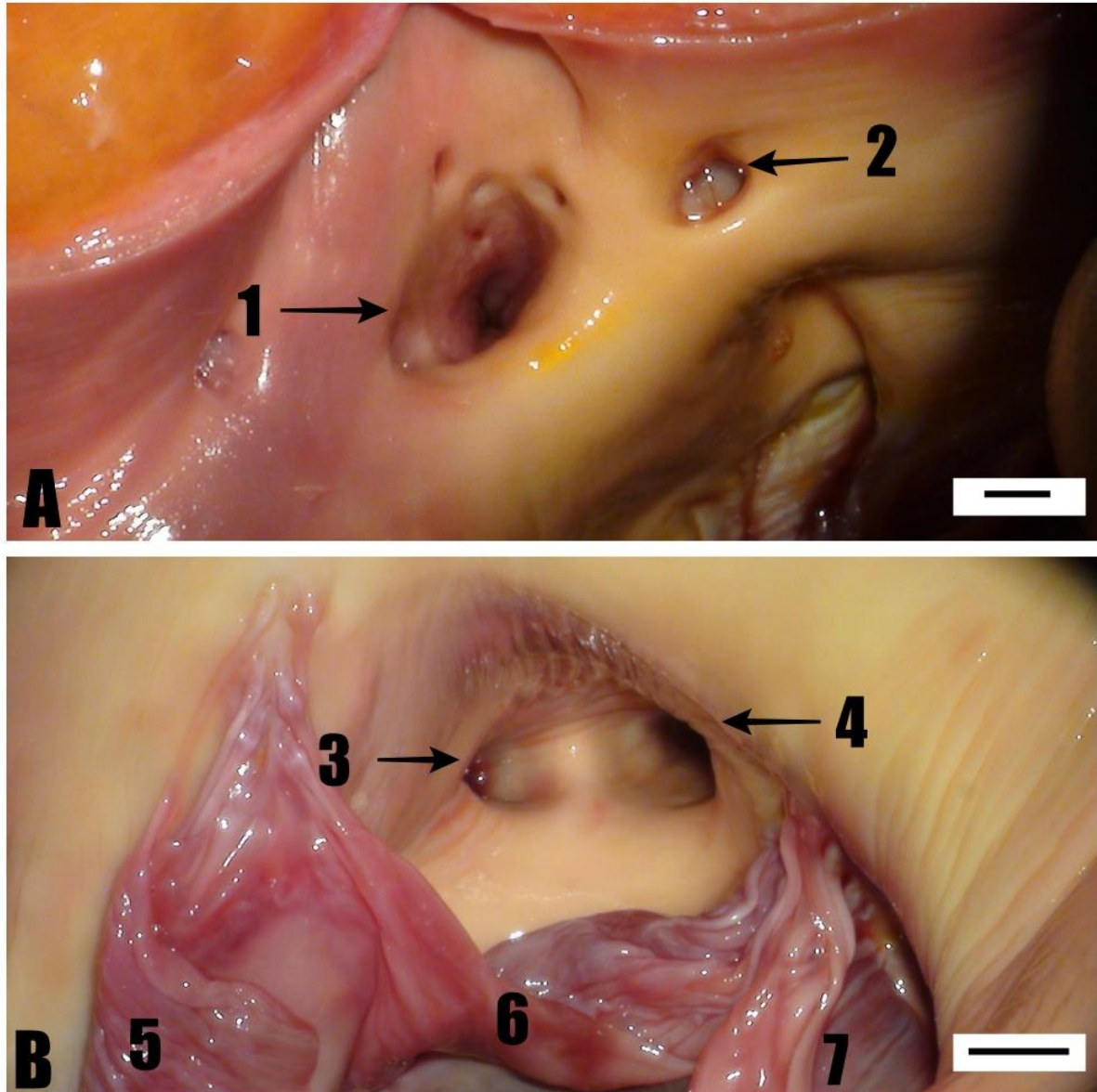


Figure 2. Overview of the aortic valve. A – additional coronary ostium in the left aortic sinus, B – lack of the main trunk of the left coronary artery. 1 – the left coronary ostium, 2 – the additional coronary ostium, 3 – the left circumflex branch, 4 – the paraconal interventricular branch, 5 – the septal semilunar leaflet, 6 – the left semilunar leaflet, 7 – the right semilunar leaflet. Scale bar 5 mm.

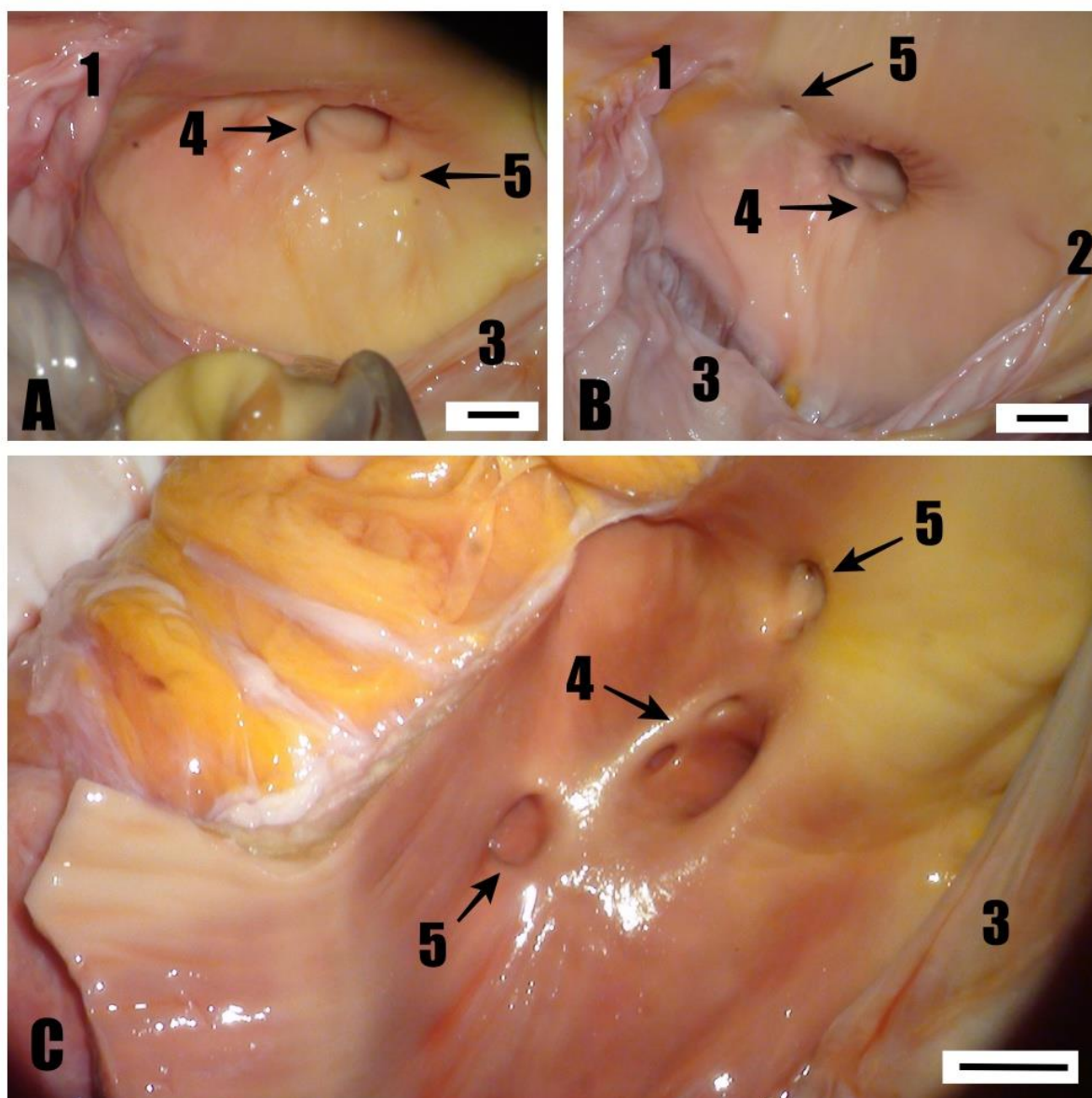


Figure 3. Overview of the aortic valve. A, B, C – the additional coronary ostia in the right aortic sinus. 1 – the intermediary aortic valve commissure, 2 – the right aortic valve commissure, 3 – the right semilunar leaflet, 4 – the right coronary ostium, 5 – the additional coronary ostium. Scale bar 5 mm

Table 1. Measurements of the coronary ostia. LCA – the left coronary ostium, RCA – the right coronary ostium

Ostium dimension	LCA	RCA	p-value (paired t-test)
Overall (n=27)			
Length [mm]	10.9±3.3 (3.4-17.3)	6.4±1.9 (2.9-9.8)	<0.001

Width [mm]	6.2±1.9 (2.5-10.0)	4.6±1.7 (1.7-8.9)	<0.001
Area [mm ²]	113.6±58.4 (13.2-248.2)	50.4±31.5 (7.9-136.5)	<0.001
Young bison (≤5 years) (n=14)			
Length [mm]	9.1±3.1 (3.4-13.8)	5.4±2.0 (2.9-9.8)	<0.001
Width [mm]	5.5±1.9 (2.5-8.8)	4.0±1.7 (1.7-7.5)	0.002
Area [mm ²]	85.5±52.2 (13.2-190.0)	38.9±31.7 (7.9-114.3)	0.001
Adult bison (>5 years) (n=13)			
Length [mm]	12.8±2.3 (9.1-17.3)	7.4±1.4 (5.0-9.8)	<0.001
Width [mm]	7.1±1.7 (5.0-10.0)	5.3±1.4 (3.7-8.9)	0.004
Area [mm ²]	143.8±50.2 (87.3-248.2)	62.8±27.3 (30.8-136.5)	<0.001