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Anatomy of the coronary arteries in Eurasian wild boar (*Sus scrofa*)

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Abstract

Coronary circulation determines the proper functioning of the heart muscle and blood circulation in the body. Cardiovascular diseases in humans are creating an ever-increasing demand for more research into their pathogenesis, diagnosis and treatment.

Animal models of organs are an indispensable part of research for the development of human medicine. Due to the high genetic similarity, the most commonly used donor is the domestic pig. The Eurasian wild boar is the ancestor of the domestic pig and an invasive species not covered by European protection programmes. Given its analogous structure and genotype to the pig, it could potentially also become an organ donor.

The aim of this study was to analyse the normal coronary anatomy of the Eurasian wild boar and compare it to humans, domestic pigs and other animal species.

The study was conducted on 60 wild boar hearts. Twenty-eight slides were prepared using acrylic, while liquid latex was injected into 32 hearts. The blood vessels were then manually prepared using surgical instruments for examination.

Both the right coronary artery and the left coronary artery of the boar diverge from the ascending aorta from opposite aortic sinuses. The left coronary artery begins its course in the left aortic sinus, starting between the left appendage and the pulmonary trunk. It then heads inferiorly. The right coronary artery supplies blood to the right atrium and right ventricle.

The study points to the wild boar coronary system's individual morphological features and notes the common arterial patterns in mammals.

Running title: Eurasian wild boar - the coronary arteries

Keywords: animal anatomy, heart, Sus scrofa, Eurasian wild boar, coronary circulation, coronary artery

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Introduction

The coronary arteries of the heart are at the heart of many circulatory system diseases, e.g. ischaemic heart disease (*morbus ischaemicus cordis*), which occurs mainly in humans [1].

The coronary circulation (*circulatio coronalis*), both arteries (*arteriae coronariae*) and venous (*venae coronariae*), function as the private blood supply of the heart [2]. It supplies the myocardial cells with oxygenated blood and substances to ensure the proper functioning of the entire heart, whose role is to supply oxygen to other parts of the body via major and minor circulation [3].

Animal models of the heart play a fundamental role in the development of human medicine through their use in research into the pathogenesis, diagnosis and treatment of various cardiovascular conditions [4]. A detailed analysis of the anatomical structure of the heart muscle of the suiformes (Suina) may be of interest to medical researchers, given the genetic similarity of this suborder with humans [5] and also, their common tendency to diseases [6] located in groups I20-I25 according to the ICD-10 International Classification of Diseases [7].

The Eurasian wild boar (*Sus scrofa*), which is the subject of our study, is the ancestor of the domestic pig (*Sus domestica*) [8], currently used as a donor in xenotransplantology for, among other things, heart valves [9]. The Eurasian wild boar, due to the fact that they belong to the game and are also a species of least concern (LC; Least Concern) according to the International Union for Conservation of Nature [10], represent a large pool of potential research material.

Given the use of pigs as organ donors, it is possible that the Eurasian wild boar could also be used as an organ donor. Learning more about the anatomy of its coronary system is important to increase the knowledge available to scientists and surgeons so that the pool of available hearts for transplantation can be realistically multiplied.

The aim of this study is to provide an overview of the normal anatomy of the coronary vessels of the Eurasian wild boar and to compare it to humans, domestic pigs and other animal species.

Materials and methods

The study was conducted on 60 Eurasian wild boar hearts showing no pathological changes visible to the naked eye. The animals were of both sexes, weighing 43-61 kg carcasses. The material was obtained by hunting. The specimens analysed

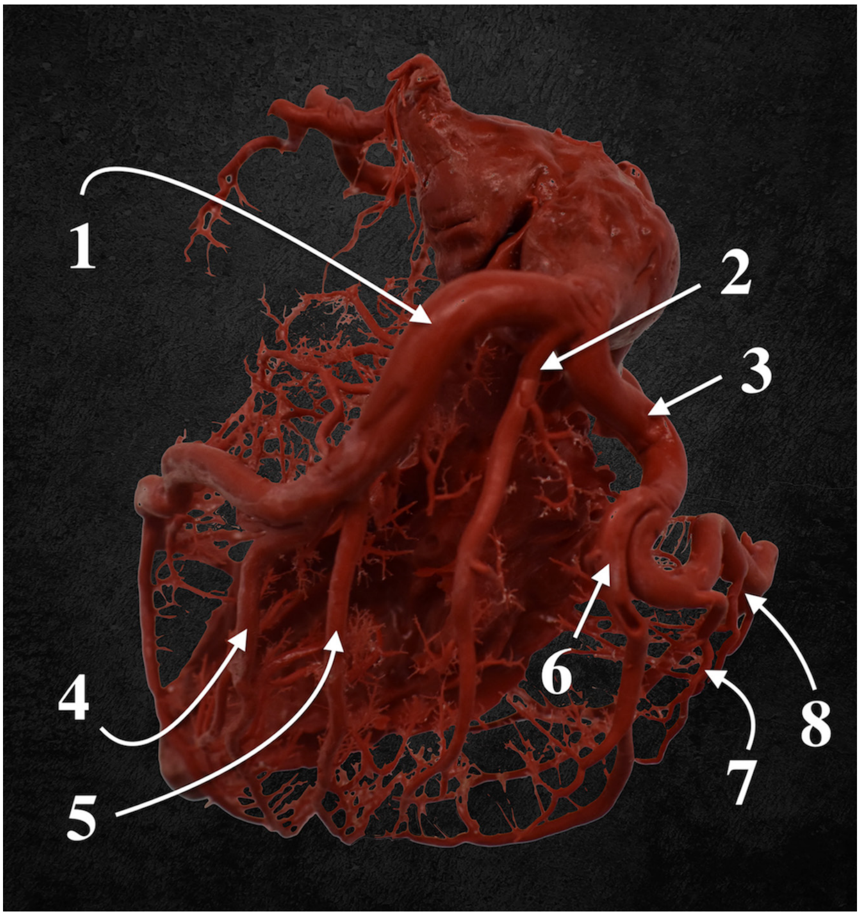

FIGURE 1 The left coronary artery. Corrosion cast. 1 - *r. interventricularis paraconalis*, 2 - *r. angularis*, 3 - *r. circumflexus*, 4 - *r. collateralis distalis*, 5 - *r. collateralis proximalis*, 6 - *r. proximalis ventriculi sinistri*, 7 - *r. marginis ventricularis sinistri*, 8 - *r. distalis ventriculi sinistri*

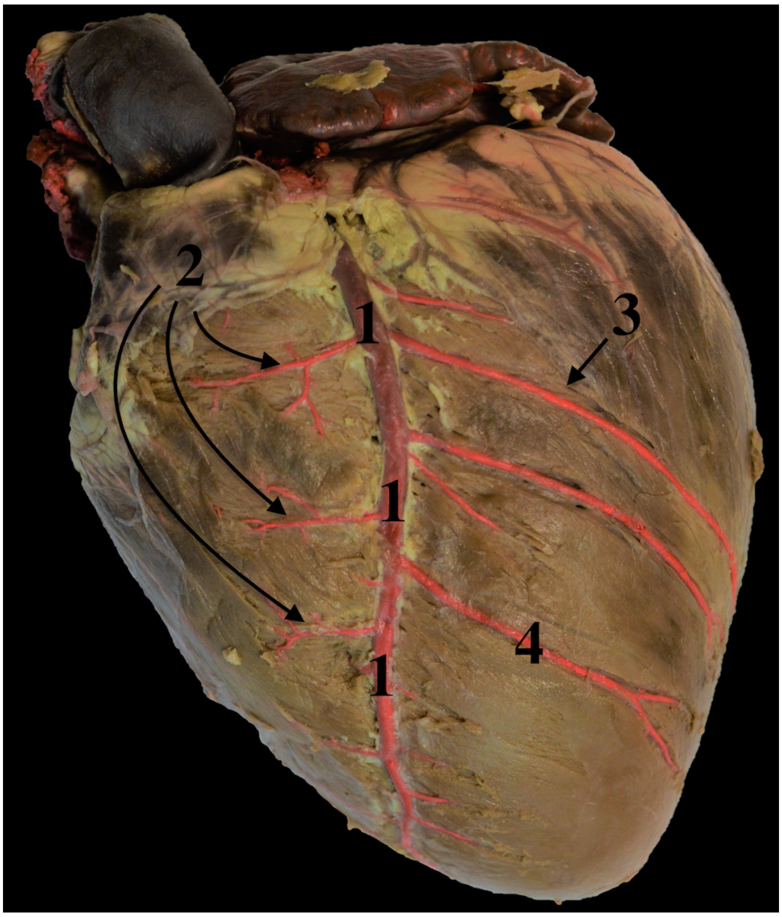

FIGURE 2 The left coronary artery. Latex method. 1 - *r. interventricularis paraconalis*, 2 - *rr. ventriculares dextri*, 3 - *r. collateralis proximalis*, 4 - *r. collateralis distalis*

did not show any signs of damage to the material as a result of being shot.

Twenty-eight specimens were prepared by injecting DURACRYL® PLUS (Spofa Dental) coloured, chemically curable acrylic into the aorta. The specimens were cured after approximately 20 min. The material was then enzymatically macerated with Persil powder (Henkel) at 40°C for about three weeks. This procedure resulted in vascular corrosion casts. Thirty-two specimens were prepared using a different method. Liquid red latex LBS 3060 was introduced into the aorta. The material was then immersed in a 5% formalin solution, where it hardened after seven days. The arteries were manually dissected using surgical instruments to observe the coronary system. The images were taken with a digital camera and then edited graphically.

The names of the anatomical structures were standardised according to Nomina Anatomica Veterinaria [11].

Results

Both the right coronary artery (*arteria coronaria dextra*) and the left coronary artery (*arteria coronaria sinistra*) of the Eurasian wild boar diverge from the ascending aorta (*aorta ascendens*) from opposite sinuses of the aorta (*sinus aortae*) often referred to as the sinuses of Valsalva. The diameters of the two vessels differ slightly, but the left coronary artery shows a larger diameter than the right coronary artery.

The left coronary artery begins its course in the left aortic sinus, starting between the left auricle (*auricula cordis sinistr*a) and the pulmonary trunk (*truncus pulmonaris*). This segment is surrounded by abundant adipose tissue. It then heads inferiorly, dividing into the circumflex branch (*ramus circumflexus*) and the paraconal interventricular branch (*ramus interventricularis paraconalis*), as well as the angular branch (*ramus angularis*) (**Fig. 1**).

The circumflex branch lies in the coronary sulcus under the left auricle, continuing in the subsinuosal interventricular sulcus (*sulcus interventricularis subsinuosus*), heading towards the apex cordis. The circumflex branch anatomically supplies the area of the left upper heart, branching off in some places as anastomoses. Three branches of the circumflex branch follow the left ventricular wall (*ventriculus sinister*): the proximal lateral branch of the left ventricle (*r. proximalis ventriculi sinistri*), the marginal branch of the left ventricle (*r. intermedius s. marginis ventricularis sinistri*) and the distal branch of the left ventricle (*r. distalis ventriculi sinistr*i). Ana-

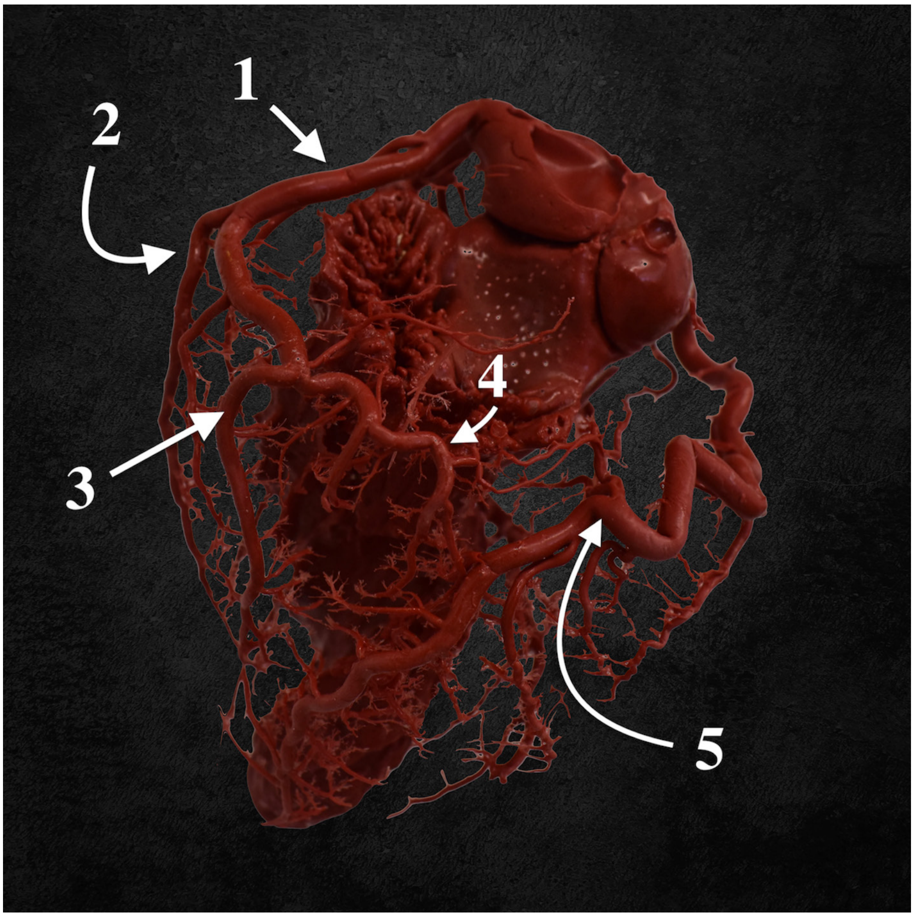

FIGURE 3 The circumflex branches of the left and right coronary arteries. Visible anastomosis of the main coronary arteries. Corrosion cast. 1 - *a. coronaria sinistra, r. circumflexus*, 2 - *r. proximalis ventriculi sinistri*, 3 - *r. intermedius s. marginis ventricularis sinistri*, 4 - *r. distalis ventriculi sinistri*, 5 - *a. coronaria dextra, r. circumflexus dexter*

logous to the left atrium (*atrium cordis sinistrum*) is the proximal branch of the left atrium (*r. proximalis atrii sinistri*), as well as the intermediate branch of the left atrium (*r. intermedius atrii sinistri*).

The paraconal interventricular branch lays in the paraconal interventricular sulcus (*sulcus interventricularis paraconalis*), heading towards the apical notch of the heart (*incisura apicis cordis*) (**Fig. 2**). Our study showed that in 11 preparations, this branch penetrates to a small extent into the subsinouosal interventricular sulcus. Very numerous peripheral divisions characterise this vessel. Some lay on the right ventricular wall (*ventriculus dexter*), and they are shorter but more branched secondarily than those heading for the left ventricular wall. Among the more important branches is the branch of the conus arteriosus (*r. coni arteriosi*), which in 33 specimens anastomosed with the branch diverging from the right coronary artery. The proximal collateral branches (*r. collaterales proximales*) and the distal collateral branches (*r. collaterales distales*) are also located on the left ventricular wall and head towards the apex of the heart. These are the largest of all branches in the left ventricular wall. In addition, the paraconal interventricular branch bifurcates into 7-14 septal branches (*r. septales*), which supply ⅔ of the anterior part of the interventricular septum (*septum interventriculare*). In most of the hearts studied, the second septal branch had the largest diameter because it supplies the papillary muscle (*musculus papillaris*).

The angular branch was present in 37 preparations. In 17, it was expressed with a very small diameter without secondary divisions. The rest of the material examined contained this vessel in a stronger and more expressed form, bifurcating into numerous branches.

The right coronary artery begins in the right aortic sinus lying between the right auricle (*auricula cordis dextra*) and the arterial conus (*conus arteriosus*). It supplies blood to the right atrium via the intermediate branch of the right atrium (*r. intermedius atrii dextri*) and the distal branch of the right atrium (*r. distalis atrii dextri*). The following branches are directed to the ventricular wall: the conus arteriosus branch, proximal right ventricle branch (*r. proximalis ventriculi dextri*), marginal right ventricle branch (*r. intermedius ventriculi dextri s. r. marginis ventricularis dextri*), distal right ventricle branch (*r. distalis ventriculi dextri*) (**Fig. 3, 4**).

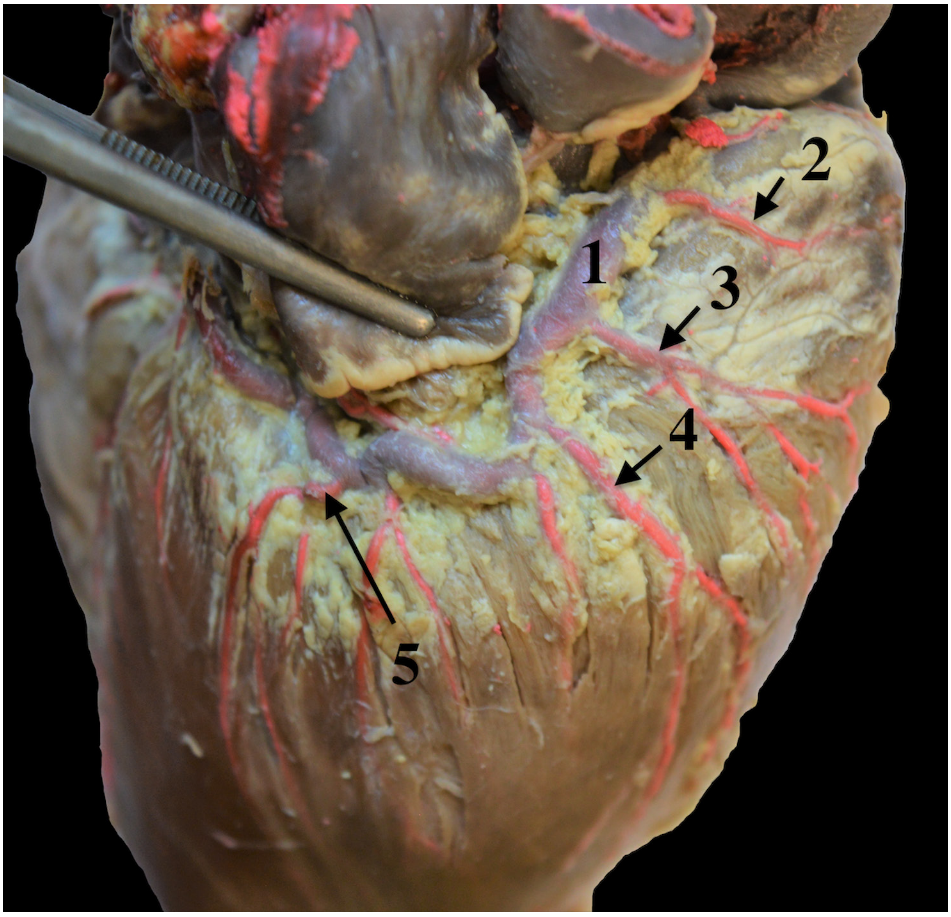

FIGURE 4 The right coronary artery. Latex method. 1 - *r. circumflexus*, 2 - *r. coni arteriosi*, 3 - *r. proximalis ventriculi dextri*, 4 - *r. marginis ventricularis dextri*, 5 - *r. distalis ventriculi dextri*

It continues into the subsinuosal interventricular sulcus on the atrial surface of the heart (*facies atrialis*) as the subsinuosal interventricular branch (*ramus interventricularis subsinosus*) (**Fig. 5**). This vessel shows numerous anastomoses on the auricular surface of the heart (*facies auricularis*), and some of these anastomoses connect to vessels diverging from the left coronary artery. From the subsinuosal interventricular branch, up to 6 vessels branched off to the right ventricular wall, and 1-4 small vessels branched off to the left ventricle. Moreover, the septal branches supply ⅓ of the posterior part of the septum. Some vessels supplying the interventricular septum show anastomoses with vessels of the left coronary artery.

Discussion

As reported in Nomina Anatomica Veterinaria [11], both coronary arteries branch off from the aortic sinus in domestic animals. The right coronary artery in the domestic horse (*Equus caballus*) and domestic pig gives off a branch in the form of the subsinuosal interventricular branch, which then branches into the septal branches. In the domestic cat (*Felis catus*), the right coronary artery, after leaving the aortic sinus of the right semilunar valve cusp, runs in the coronary sulcus, calling itself the right circumflex branch [12]. A right accessory coronary artery (*a. coronaria dextra accessoria*) has also been observed in the domestic dog (*Canis familiaris*), which is rarely seen and runs very similar to the main right coronary artery except that it atrophies heading to the arterial conus [13].

The left coronary artery bifurcates into the paraconal interventricular branch, which forms the septal branches. The second branch of the left coronary artery is the circumflex branch, which extends into the intermediate branch (*ramus intermedius*). In dogs and ruminants (Ruminantia), the subsinuosal interventricular branch bifurcates into septal branches. In the domestic cat, the subsinuosal interventricular branch can originate from both the circumflex branch of the right coronary artery and the circumflex branch of the left coronary artery [11].

Double coronary arteries in vascular variants occur in humans [14]. Cases of a single coronary artery in humans have also been described as a consequence of a genetic defect [15]. An analogous vascular variant, i.e. the presence

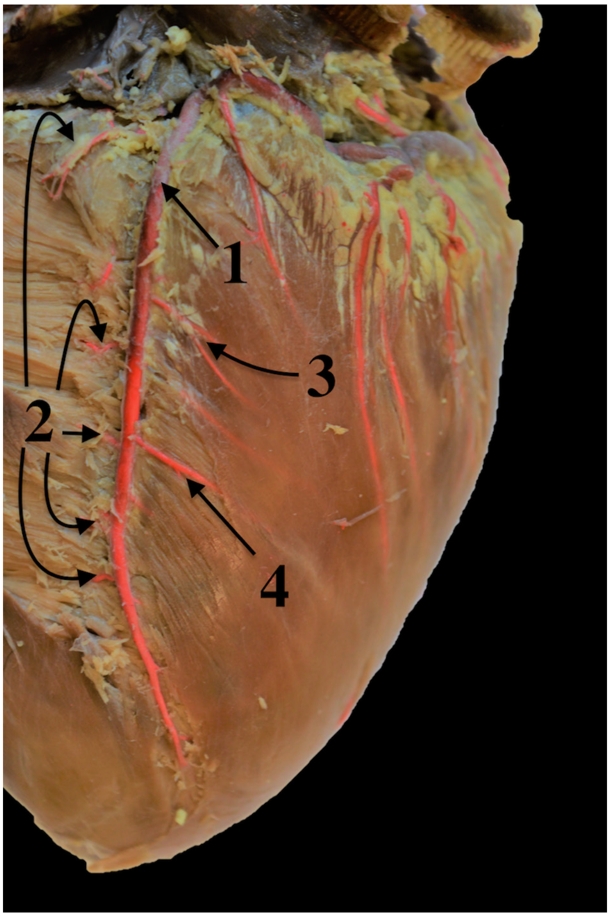

FIGURE 5 The right coronary artery. Latex method. 1 - *r. interventricularis subsinosus*, 2 - *rr. collaterales ventriculi sinistri*, 3 - *r. collateralis proximalis*, 4 - *r. collateralis distalis*

of only one coronary artery, has also been observed in the long-tailed chinchilla (*Chinchilla lanigera*) [16].

In the morphologically normal human heart, the course of the left coronary artery appears similar to that of a wild boar heart. The left coronary artery at the terminal division bifurcates into the anterior interventricular branch (*ramus interventricularis anterior*) and the circumflex branch. The anterior interventricular branch gives off three side branches: right, left, and septal. The right-hand branch includes the branch of the conus arteriosus, which is also found in the wild boar. This branch forms an anastomosis with the vessel of the right coronary artery. On the other hand, the circumflex branch gives off ascending or atrial branches supplying the left atrial wall and the posterior wall. The descending branches are designed to supply the left ventricle and are larger than the ascending branches. The right coronary artery branches into the posterior interventricular branch (*ramus interventricularis posterior*), which reaches the apex of the heart and then gives off right and left lateral branches and posterior septal branches. The second branch runs further into the coronary sulcus in an extension of the main trunk. However, Bochenek and Reicher [17] do not give it an anatomical name, referring to it as the 'second branch'. In addition, there are smaller branches, such as ascending branches supplying the anterior and posterior walls of the right atrium and descending branches called ventricular branches [17].

Like humans, the European bison (*Bison bonasus*) shows a division of the left coronary artery into the circumflex branch and the paraconal interventricular branch. However, in a few cases, an additional third branch is present. The right coronary artery of the European bison is anatomically not significantly different compared to the wild boar [18]. In the domestic goat (*Capra hircus*), the occurrence of both arteries is similar, but a third branch diverging from the left coronary artery is not present [19]. As reported by Frąckowiak et al. [20] in a study of the coronary vessels of the roe deer (*Capreolus capreolus*), the left coronary artery branches into a very strong paraconal interventricular branch and a circumflex branch. The former gives off: the proximal collateral branch, the distal collateral branch, the septal branches and the left arterial conus branch. The circumflex branch gives off the left ventricular proximal branch, the left ventricular marginal branch and the distal branch. The right coronary artery of the roe deer gives off the right branch of the arterial cone, the proximal branch of the right ventricle and the distal branch of the right ventricle. Research conducted on ruminants showed no significant differences in the anatomy of this area [18-20].

As reported by Yuan et al. [21], the branches of the left coronary artery of the Bactrian camel (*Camelus bactrianus*) show no significant differences in branching except for the absence of an angular branch. Yuan et al. [21] also confirm that the left coronary artery has a larger diameter and that the left circumflex branch does not anastomose with the right circumflex branch, which was the case in most specimens examined in our study. The right coronary artery of the camel had no anatomical structures relevant to this study.

An interesting aspect concerning the coronary arteries is the formation of collateral circulation as an adaptation to stenosis or complete occlusion of one of the coronary arteries [22]. Depending on the species, the collateral circulation is differently developed, better or weaker [23]. In the case of rodents, mainly rats, they are at high risk of complications related to coronary stenosis because they have a high heart rate, in the range of 200 to even 500 beats per minute [24]. Only the guinea pig (*Cavia porcellus*), which is distinguished by a very well-developed peripheral circulation that ensures proper perfusion, is less susceptible to myocardial vascular disorders, while there are large breed disparities among lagomorphs [25]. Dogs and cats, like the guinea pig, have a very well-developed collateral circulation, and infarction in them occurs more than half an hour after cardiac arrest in a given coronary artery [26]. The collateral circulation is little developed in pigs, where signs of infarction are visible after several minutes, and cardiac death can occur within 45 minutes [27].

In their study, Yuan et al. [21] define the classification of coronary artery branching into two classes: group A, in which the subsinuosal interventricular branch originates from the left coronary artery. This situation occurs in bovines, sheep, goats, dogs and cats [28-32]. It also distinguishes group B, where the mentioned vessel is a branch of the right coronary artery, as in the horse, pig, camel and donkey [28,33-36]. It should be noted that in both groups, the paraconal interventricular branch is a branch of the left coronary artery. Considering the assumptions of Yuan et al. [21], the Eurasian boar should be classified in group B.

Coclusions

The coronary system in the Eurasian wild boar is made up of two main arteries: the right coronary artery and the left coronary artery, which has a larger diameter. The coronary arteries had a tortuous course, which is probably an adaptation to the heart's workings. In addition, such a course slows down the flow, resulting in a better exchange of substances. More delicate branches led deep into the heart muscle from the vessels supplying the heart ventricles. The right ventricle showed shorter branches than the left ventricle due to the thickness of the wall. The left atrium was characterised by more small vessels compared to the right atrium. There was an angular branch from the left coronary artery, which is not anatomically standard in mammals. The left branch of the arterial conus anastomoses with the right branch of the arterial conus in most of the material studied. Although there is extensive thematic literature in the context of mammalian cardiac coronary anatomy, this study demonstrated the individual and species-specific morphology of the coronary system of the Eurasian wild boar heart.

Ethical approval

The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals. As the research material was collected posthumously, no Ethical Committee approval is needed for this study.

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Not applicable.

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Conflicts of interest

The authors declare they have no conflict of interest.

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