



# Topography of coronary arteries and their ramifications in the goat

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## Abstract

The aim of this study was to investigate the morphology of the coronary arteries of the goat's heart. The study was carried out on 36 hearts of adult females dairy goats, belonging to two breeds, aged 7–12 years, with an average body weight of 37 kg. A distinct view of coronary arteries and their branches was obtained by filling them with dyed synthetic latex (LBS 3060) or Batson's No. 17. In all studied goats the common trunk of the left coronary artery was divided into the interventricular paraconal branch and the circumflex branch. The branch of the interventricular septum originated in the interventricular paraconal branch. In 25 individuals (69%) the circumflex branch ended with small ramifications on the atrial surface of the heart. In 11 individuals (31%), the vessel extended in the subsinuosal interventricular groove into the subsinuosal interventricular branch. The right coronary artery was less developed than the left coronary artery. In 35 individuals (97%) the right coronary artery ended with small ramifications on the atrial surface of the heart. In one goat (3%) the vessel reached the subsinuosal interventricular groove and extended into the subsinuosal interventricular branch.

**Keywords** Coronary arteries · Corrosion castings · Goat · Heart · Vascular casting

## Introduction

Coronary vessels have been studied in domestic and wild ruminants including Angora and Akkamaran goats (Besoluk and Tipirdamaz 2001), roe deer (*Capreolus capreolus* Linnaeus, 1758) (Frąckowiak et al. 2007), Bactrian camel (*Camelus bactrianus* Linnaeus, 1758) (Yuan et al. 2009), one-humped camel (*Camelus dromedarius* Linnaeus, 1758) (Ghazi and Tadjalli 1993), European bison (*Bison bonasus* Linnaeus, 1758) (Kupczyńska et al. 2015). However, the available literature provides little information on the topography of coronary arteries and their ramifications in the goats

(*Capra hircus* Linnaeus, 1758) (Nickel et al. 1981; Barone 1996; Besoluk and Tipirdamaz 2001). More information on its anatomy is needed. Because of the anatomical similarity between the goats and other ruminants, the results of this study can be applied also to the other species.

Goats are a commonly accepted species for biomedical study. The similarity of organ size between goats and humans makes these animals widely used. They are used in human medicine in research such as cardiac, orthopedic, model for infectious diseases or many others (Shiraishi et al. 2012; Chen et al. 2015; Zhang et al. 2015; Lukovsky-Akhsanov et al. 2016; Du et al. 2018; Vandersteene et al. 2018).

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The aim of this study was therefore to investigate the morphology of the coronary arteries of the goat's heart.

## Material and methods

The study was carried out on 36 hearts of adult females dairy goats aged 7–12 years, belonging to two breeds – Polish Fawn Improved ( $n = 20$ ) and Polish White Improved ( $n = 16$ ), closely related to French Alpine and Saanen, respectively. Body weight ranged from 20 to 49 kg (mean 37 kg). Pathological examination of the whole body was performed before the dissection of the hearts. None of the animals included in the study had any pathological changes in the thoracic cavity. Nomenclature from the *Nomina Anatomica Veterinaria* (2017) was used.

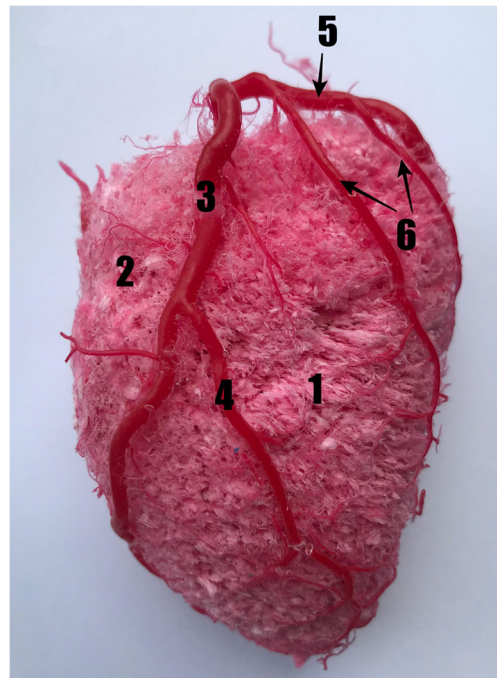
Coronary arteries were visualized by filling them through the aorta with Latex (LBS 3060) (Synthos Dwory Sp. z o.o, Poland) with additional dye (INCHEM) or Batson's No. 17 (Polyscience, Incorporation, Warrington, US). The hearts ( $n = 26$ ) filled with the latex injection mass were placed in a 4% formaldehyde solution. Next, the proximal segments of the left and right coronary arteries were dissected. Corrosion castings were prepared by filling selected hearts ( $n = 10$ ) with colored resin. The specimens were then left at room temperature ( $>18\text{ }^{\circ}\text{C}$ ) until the casts hardened. Next, to dissolve the organic tissue, the materials were placed in 40% KOH solution at  $50\text{ }^{\circ}\text{C}$  for approximately 24 h. The remnants of the tissue were removed by continuous flushing with water for 38 h and then the material was cleaned by water and a small amount of standard washing liquid. The cast was later dried at room temperature for 48 h. These methods of injection were successfully used in our previous studies (Polgaj et al. 2009, 2011; Barszcz et al. 2014, 2016a, 2017; Kupczyńska et al. 2015).

## Results

### Morphology of the left coronary artery

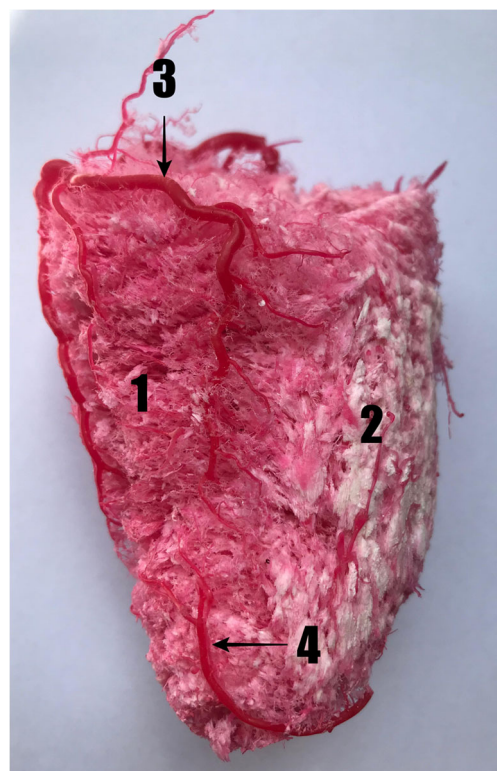
In all studied goats heart the left coronary artery (*A. coronaria sinistra*) originated in the aortic sinus above the left semilunar cusp. The trunk of this vessel was short and located at the coronary groove between the left atrium and the pulmonary trunk. As often as not, the common trunk was divided into: a stronger paraconal interventricular branch (*r. interventricularis paraconalis*) and a weaker circumflex branch (*r. circumflexus*) (Fig. 1).

The paraconal interventricular branch was a strong vessel which was branched from the left coronary artery. First, it ran towards the paraconal interventricular groove as the descending part, and next proceed to the atrial surface of the heart as the ascending part (Figs. 1 and 2).



**Fig. 1** The auricular surface of the heart. 1 – left ventricle, 2 – right ventricle, 3 – paraconal interventricular branch (descending part), 4 – intermediate collateral branch, 5 – circumflex branch, 6 – proximal branch of the left ventricle

The descending part of the paraconal interventricular branch ran on the auricular surface of the heart. Usually it



**Fig. 2** Atrial surface of the heart. 1 – left ventricle, 2 – right ventricle, 3 – circumflex branch, 4 – paraconal interventricular branch (ascending part)

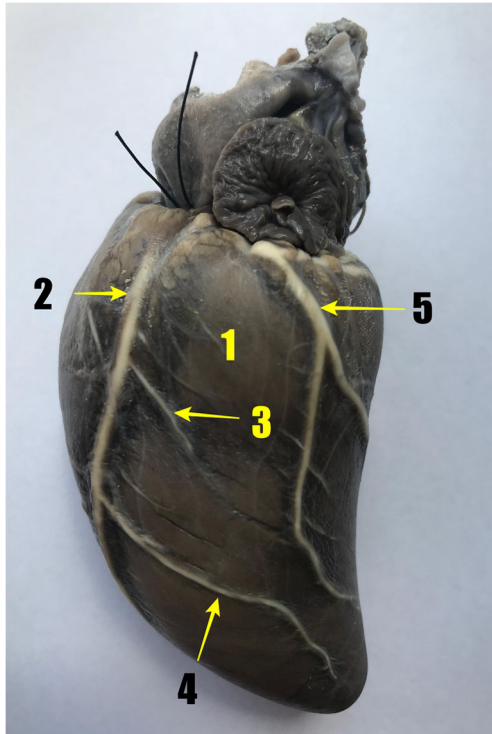
divides into the left conal branch, (*r. coni arteriosi sinister*), the proximal, intermediate and distal collateral branches, (*r. collateralis proximalis, intermedius et distalis*), also the septal branches, (*rr. septales*) and lots of small vessels to the lateral walls of both ventricles on the auricular heart's surface. We observed also the branch of the interventricular septum which originated from the paraconal interventricular branch.

In all studied goats, we observed that:

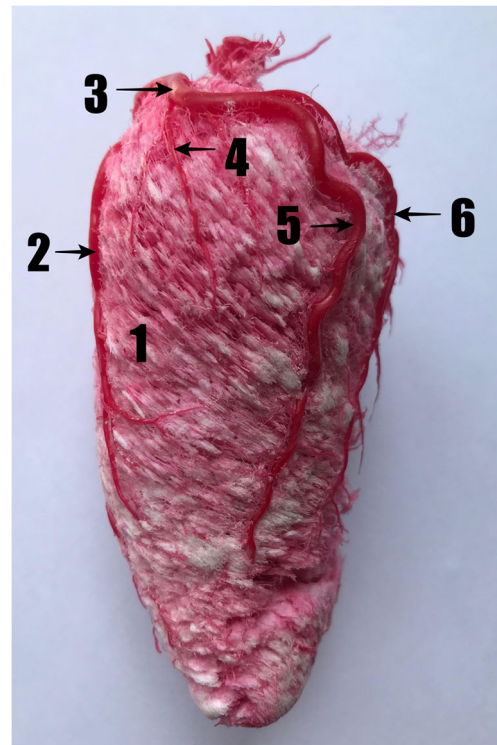
- the left conal branch, originated from the right side of the paraconal interventricular branch,
- the proximal collateral branch was the smallest lateral vessel,
- the intermediate collateral branch in most cases (26 individuals, 72%), was well developed. It was presented as clear and strong vascular trunk (Figs. 1 and 3). The intermediate collateral branch originated from the left side of the main stem, in the middle of the paraconal interventricular groove and supplied the left ventricle wall,
- the distal collateral branch, also was well developed and originated from the left side of the paraconal interventricular branch, and its ramifications runs to the left ventricular border supplying the left ventricle wall in the vicinity of the apex of the heart (Fig. 3),
- the paraconal interventricular branch extended as the ascending part on the atrial surface of the heart from notch

- of cardiac apex. It sent multiple vessels to the interventricular septum and to the lateral walls of both ventricles,
- the small septal branches were also present along the paraconal interventricular branch,
- there were also many small right and left ventricular branches, which supplied the walls of respective ventricles.

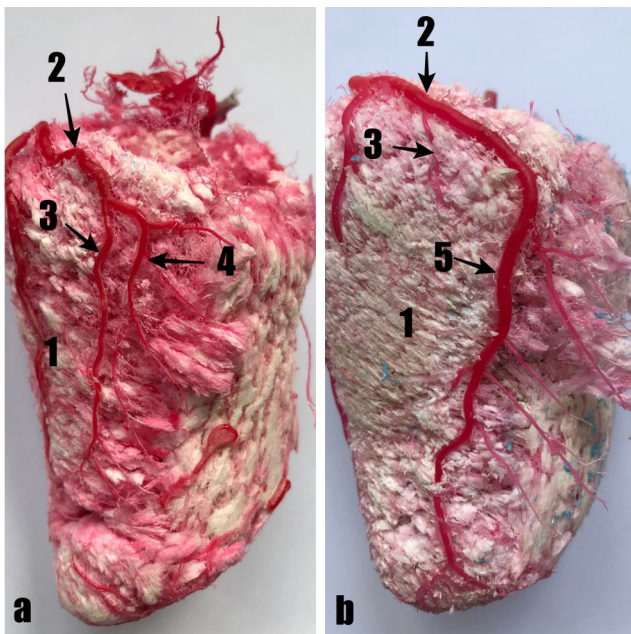
The circumflex branch was the continuation of the left coronary artery. In the beginning, it lied in the coronary groove on the auricular surface. Afterwards it ran to the atrial surface of the heart (Figs. 1, 2, 4 and 5). In most cases (25 individuals, 69%), it ended with small branches on the atrial surface of the heart (Fig. 5a). In 11 individuals (31%), the circumflex branch extended as the subsinuosal interventricular branch. It passed in the subsinuosal interventricular groove where it gave off small branches participated in vascularizing the lateral wall of both ventricles (Fig. 5b). From the circumflex branch arise several vessels supplying the left ventricle and left atrium, there were: the proximal branch of the left ventricle, (*r. proximalis ventriculi sinistri*), the branch of the left ventricular border, (*r. marginis ventricularis sinistri*), the distal branch of the left ventricle, (*r. distalis ventriculi sinistri*), the proximal, intermediate and distal branch of the left atrium, (*r. proximalis,*



**Fig. 3** The auricular surface of the heart. 1 – left ventricle, 2 – paraconal interventricular branch (descending part), 3 – intermediate collateral branch, 4 – distal collateral branch, 5 – proximal branch of the left ventricle



**Fig. 4** The left ventricular border of the heart. 1 – left ventricle, 2 – paraconal interventricular branch, 3 – circumflex branch, 4 – proximal branch of the left ventricle, 5 – branch of the left ventricular border 6 – distal branch of the left ventricle



**Fig. 5** The atrial surface of the heart (**a** and **b**). 1 – left ventricle, 2 – circumflex branch, 3 – distal branch of the left ventricle, 4 – final branch of the circumflex branch, 5 – subsinuosal interventricular branch in subsinuosal interventricular groove

*intermedius et distalis atrii sinistri*) and also numerous small ramifications (Figs. 1, 3 and 4).

Our study showed that:

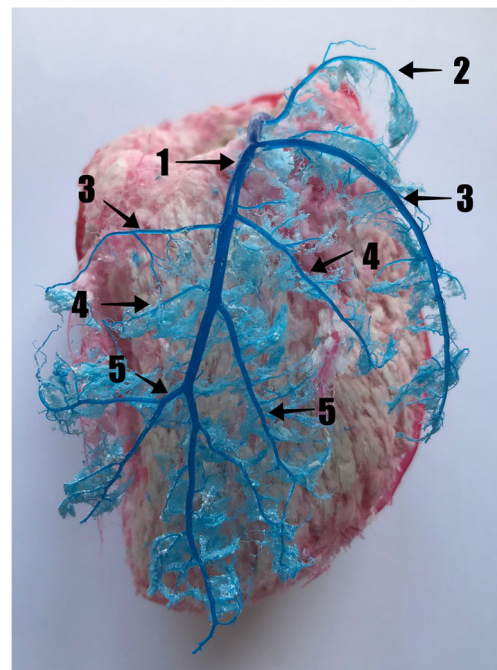
- the proximal branch of the left ventricle in 19 goats (53%) was very well developed (Fig. 3), in 16 individuals (44%) was poorly developed, while one goat (3%) had two well-developed proximal branches (Fig. 1). It arose from the ventral side of the circumflex branch and passed caudo-ventrally through the auricular surface to the cardiac atrial surface where it gave off several branches to the lateral wall of the left ventricle and to the apex of heart,
- the branch of left ventricular border originated from the left circumflex branch near the left auricle (Fig. 4). It gave off small branches to the auricular surface of the heart,
- the distal branch of the left ventricle originated from the ventral side of the circumflex branch and lied ventrally close to the left ventricular border. Their ramifications supplied the walls of the left ventricle on the atrial surface of the heart (Figs. 4 and 5a),
- the branches for the left atrium were very small and originated from the medial wall of the circumflex branch,
- the proximal branch of the left atrium, passed on the left atrium near to the base of heart,
- the intermediate branch of the left atrium, originated close to the branch of the left ventricular border,
- the distal branch of the left atrium, was the weakest branch of the circumflex branch,

- apart from the described vessels, we observed also the numerous weakly developed arteries originating from the circumflex branch and vascularizing the left ventricle and left atrium. There were the left ventricular branches and the left atrial branches.

### Morphology of the right coronary artery

The right coronary artery (*A. coronaria dextra*) was less developed than the left coronary artery (Fig. 6). In all studied goat's heart it arose from aortic sinus above to the right semi-lunar cusp. The vessel was located into the coronary groove between the right auricle and the pulmonary trunk. Next it reached the right ventricular border and gave off ramifications to the right atrium and right ventricle. In 35 individuals (97%) the right coronary artery ended as a small ramifications on the atrial surface of the heart. Only in one case (3%) the right coronary artery prolonged as the subsinuosal interventricular branch and ran in the subsinuosal interventricular groove.

In our goat's studies the several vessels arise from the right coronary artery. There were: the right conal branch (*r. coni arteriosi dextra*), the proximal, intermediate and distal collateral branch (*r. collateralis proximalis, intermedius et distalis*) and also numerous small ramifications to the lateral walls of the right ventricle on the atrial surface of the heart (Fig. 6). In all specimens the right conal branch, was continuation of the right coronary artery from its right side and surrounded the arterial cone. We observed also that all collateral branches of



**Fig. 6** The atrial surface of the heart. 1 – right coronary artery, 2 – right conal branch, 3 – proximal collateral branch, 4 – intermediate collateral branch, 5 – distal collateral branch

the right coronary artery presented as a singular vascular trunks. They ran diagonally on the atrial surface of the heart where they gave off the small vessels vascularised the cardiac muscle of the right ventricle. The proximal collateral branches, were the strongest lateral vessels of the right coronary artery. They generated small branches running along the walls of the right ventricle. However the intermediate collateral branches, were poorly developed. They originated from the stem vessels, approximately half-way along the length of the right coronary artery and lied along the walls of the right ventricle. Whereas the distal collateral branches, ran from both side of the stem vessel. Their ramifications supplied the walls of the right ventricle close to the apex of heart.

## Discussion

In all studied goat's heart the common trunk of the left coronary artery was divided into two vessels. There were a stronger paraconal interventricular branch and a weaker circumflex branch. This type of trunk morphology has also been described in ruminants (Nickel et al. 1981; Barone 1996), roe deer (Frąckowiak et al. 2007), Bactrian camel (Yuan et al. 2009), donkey (Ozgel et al. 2004), porcupine (Atalar et al. 2003), ringed seal (Smodlaka et al. 2008), chinchilla (Ozdemir et al. 2008), cat (Barszcz et al. 2014, 2016b) and European bison (Kupczyńska et al. 2015). Whereas Bahar et al. (2007) reported that in the Angora rabbit, the common trunk of the left coronary artery was divided into the paraconal interventricular branch, the circumflex branch and the proximal branch of the left atrium. The additional interventricular septal branch was rarely was observed in Angora rabbit, cat and also European bison (Bahar et al. 2007; Barszcz et al. 2014; Kupczyńska et al. 2015; Barszcz et al. 2017). Moreover in all studied goats the branch of the interventricular septum originated from the paraconal interventricular branch. Observations by Barszcz et al. (2017) and Vladova (2005) showed also that in cats there were differences in terms of the origin of the septal branch of the left coronary artery. The artery usually originated from the paraconal interventricular branch although in one case it originated from the circumflex branch. Similar findings were observed in dogs (Büll and Martins 2002; Noestelhaller et al. 2007; Barszcz et al. 2013).

The paraconal interventricular branch gave off branches to the wall of the left and right ventricle of the heart. In all goats the branches to the wall of the right ventricle were significantly less developed than the branches to the wall of the left ventricle. Similar observations have been made in dog (Barszcz et al. 2013), cat (Barszcz et al. 2014) and European bison (Kupczyńska et al. 2015). In studied goat's heart the paraconal interventricular branch, ran towards the paraconal interventricular groove on the auricular surface of the heart as the descending part and next prolonged trough the notch of

cardiac apex on the atrial surface as the ascending part. These results were observed also in roe deer (Frąckowiak et al. 2007) and European bison (Kupczyńska et al. 2015). Additionally, in our study the proximal collateral branch was the smallest ramification of the paraconal interventricular branch in contract with the European bison were observed two or three well developed lateral vessels (Kupczyńska et al. 2015).

The circumflex branch in goats gave off ramifications to the left atrium and left ventricle and also small branches on the atrial surface of the heart. Our study showed that branches to the left atrium were less developed than branches to the walls of the left ventricle. Analogous observations have been made in European bison (Kupczyńska et al. 2015), Angora rabbit (Bahar et al. 2007), donkey (Ozgel et al. 2004), dog (Barszcz et al. 2013), cat (Barszcz et al. 2014), porcupine (Atalar et al. 2003). The branch of the left ventricular border in goats was clearly identifiable when the proximal branch of the left ventricle was poorly developed whereas in bison's (Kupczyńska et al. 2015), cats (Barszcz et al. 2014), ringed seal (Smodlaka et al. 2008), dogs and rabbits (Bahar et al. 2007) the branch of the left ventricular border was the largest ramification. In our study, the circumflex branch ended with small ramifications on the atrial surface of the heart or extended as the subsinuosal interventricular branch in the subsinuosal interventricular groove. The researches in roe deer and Bactrian camel showed that the circumflex branch has not entered the subsinuosal interventricular groove but ended only as small ramifications on the atrial surface of the heart (Frąckowiak et al. 2007; Yuan et al. 2009). Furthermore, observations in domestic cats by Barszcz et al. (2014) showed the three variants of arising of subsinuosal interventricular branch: it was a direct continuation of the circumflex branch of the left coronary artery or it was an extensions of the circumflex branch of the right coronary artery or observed two strong trunks of the subsinuosal interventricular branches, each departing from one or both circumflex branches. According to Vladova (2005) the subsinuosal interventricular branch in cat was a continuation of the left coronary artery. Whereas in the studies by Kupczyńska et al. (2015) the subsinuosal interventricular branch was primarily an extension of the circumflex branch of the left coronary artery and rarely it was a direct continuation of the circumflex branch of right coronary artery.

In the studied goats the right coronary artery was single and was found to be less developed than the left coronary artery. Similar observations were made in ruminants (Nickel et al. 1981; Barone 1996), roe deer (Frąckowiak et al. 2007), Bactrian camel (Yuan et al. 2009), European bison (Kupczyńska et al. 2015) and Angora rabbit (Bahar et al. 2007). However, in dog was described the additional right coronary artery (Bezuidenhout 2013) while in chinchilla the right coronary artery was absent Ozdemir et al. (2008). In our study, the right coronary artery terminated primarily as small branches on the atrial surface of the heart. In one goat, the

right coronary artery reached the subsinuosal interventricular groove and extended into the subsinuosal interventricular branch. Similar findings were made in European bison by Kupczyńska et al. (2015). Observations in bison showed that the right coronary artery usually ended in subsinuosal interventricular groove as a few small vessels or rarely it prolonged as the subsinuosal interventricular branch.

Numerous studies descriptions of the blood supply to the heart in different species of domestic and wild animals. Also in the arterial supply of the goats heart we have observed individual differences.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** The study were carried out in accordance with the local ethical committee.

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