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Research article - Basic and applied anatomy

Morphological characterization of the left coronary artery in horses. Comparative analysis with humans, pigs, and other animal species

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Abstract

Objective: To determine the anatomy expression of the left coronary artery and its branches in the horse.
Methods: The left coronary artery of 120 hearts of horse were perfused with semi-synthetic resin (85% Palatal GP40L with 15% styrene) and mineral red dye. A digital calibrator (Mitutoyo®) was used to measure the external diameter of the left coronary artery and its branches. The samples were assessed for the existence of myocardial bridges. The findings obtained were compared with those from humans, donkeys, pigs, elephants, and camels.
Results: The left coronary artery had a diameter of 6.76 ± 2.1 mm. It bifurcated into the paraconal interventricular branch and the left circumflex branch in 113 specimens (94.2%). The proximal diameter of the paraconal interventricular branch was 5.62 ± 1.97 mm, and it ended at the apex in most cases (65.8%). The left circumflex branch was short and ended as a left marginal branch in 55 samples (45.8%); its proximal diameter was 4.05 ± 1.49 mm. The sinoatrial node branch originated from the left circumflex branch in 100% of the cases. The left marginal branch was found in 92 specimens (76.7%), and ended primarily at the upper third of the obtuse margin of the heart.
Discussion: The sinus node branch emerging in all cases from the left circumflex branch differs from what has been observed in other species. Due to its similarity with the human heart, we may ratify the equine model for both procedural and hemodynamic applications.

Key words

Horse, left coronary artery, anatomical model, heart.

Introduction

Prior reports on the morphology of the left coronary artery (LCA) in horses have not described caliber, length, and trajectory of the branches of this vessel. The sparse works that describe the LCA are limited to a few imaging studies and some morphological descriptions focused on teaching animal anatomy (Rodriguez et al., 1961; Rawlings, 1977; Sisson et al., 1995).

The LCA originates from the posterior left sinus of the aorta, behind the origin of the pulmonary artery, and divides into the paraconal interventricular branch, which traverses downwards through the homonymous sulcus to end at the cardiac apex,

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and the left circumflex branch that traverses backwards through the coronary sulcus, and irrigates the obtuse margin and part of the posterior aspect of the left ventricle (Sisson et al., 1995; Ozgel et al., 2004)

In horses, donkeys, camels, and elephants the LCA divides into paraconal interventricular branch and left circumflex branch (Cave, 1936; Schummer et al., 1981; Ghazi and Tadjalli, 1993; Ozgel et al., 2004), whereas the trifurcation of the LCA has been reported in humans and pigs, along with the presence of a left diagonal branch within a range of 9-55%. (Jordão et al., 1999; Ortale et al., 2005; Ortale et al., 2005; Ballesteros and Ramirez, 2008).

Previous studies in horses failed to describe the origin of the sinoatrial node branch (Schummer et al., 1981; Thtiroff et al., 1984; Sisson et al., 1995). In pigs and humans this branch has been reported as originating primarily from the right coronary artery (RCA), followed by an origin in the left circumflex branch within a range of 30-45% (Crick et al., 1998; SAHNI et al., 2008; Gomez and Ballesteros, 2013; Ramanathan et al., 2009).

The presence of myocardial bridges variable segments of the coronary arteries embedded in the ventricular myocardium, has not been evaluated in horses (Schummer et al., 1981; Thtiroff et al., 1984; Sisson et al., 1995). In humans, pigs and camels this feature has been reported within a range of 23-88% (Kosiński et al., 2010; Babiker and Taha, 2013; Ballesteros et al., 2009). Some works have considered myocardial bridges as a risk factor for the development of certain cardiac pathological conditions (Gow, 2002; Rychter et al., 2006).

The adequate knowledge of the anatomy of the LCA in the horse allows for its use in the design of experimental anatomic and physiological models, training in hemodynamics, and for surgical procedures that use this arterial structure. This study, based on assessment on horse hearts, intends to generate meaningful information on the LCA that allows for comparing our findings, within the context of comparative anatomy, with those of humans, horses, pigs, and other animal species.

Materials and methods

This descriptive cross-sectional study assessed the LCA of 120 hearts of horses weighing 250-300 kg and being 2.5-3.5 years of age, destined to the slaughterhouse in Bucaramanga, Colombia. The organs were subjected to an exsanguination process in a water source for 6 hours. After application of a silk suture knot at its origin, the LCA was channeled through its ostium and infused with polyester resin (85% Palatal GP41L and 15% styrene) impregnated with mineral red dye. Subsequently, the hearts were subjected to a partial corrosion process with 15% potassium hydroxide (KOH) to remove the sub-epicardial fat from the interventricular and atrioventricular sulci. The size of the LCA and its branches was assessed at their origins using a digital calibrator (Mitutoyo®), their lengths were determined, and the paraconal interventricular branch was assessed for its termination at the lower third of the interventricular paraconal sulcus, the apex, or the posterior aspect of the heart. The left circumflex branch was also assessed for its ending at the obtuse margin of the heart, the posterior aspect of the left ventricle, the crux cordis, or the interventricular subsinusal sulcus. The left marginal branch was assessed for caliber, length, and ventricular segments irrigated. The LCA and its branches were assessed for the presence of myocardial bridges, determining the affected segment of the vessel, its length and the thickness of the myocardium above the bridge. Photographs were taken of each of the pieces evaluated.

Continuous variables were analyzed using Student's t test, whereas discrete variables were analyzed using Pearson's Chi^2 test. The results were evaluated using the "Epi - Info 3.5.4" statistical program. The significance level used was $p < 0.05$. Quantitative data are given as mean and standard deviation.

Results

The LCA was 11.92 ± 5.99 mm and 6.76 ± 2.1 mm in length and diameter, respectively. This artery bifurcated in paraconal interventricular branch and left circumflex branch in 113 hearts (94.2%) and trifurcated with a left diagonal branch in 7 specimens (5.8%) (Table 1) (Fig. 1).

The left diagonal branch was 2.7 ± 0.87 mm in diameter and 53.1 ± 17.3 mm in length. It ended at the middle third of the obtuse margin of the heart in 5 samples, at the upper third in one case, and at the lower third in one case. The left cone branch (LCB) was found in 53 specimens (44.2%), with a diameter of 1.93 ± 0.86, and with a distance between its source and the left coronary ostium of 40.2 ± 4.05 mm (Fig. 1).

Table 1 – Division of the left coronary artery in paraconal interventricular branch (PIB), left circumflex branch (LCXB) and left diagonal branch (LDB), by gender.

	Total sample	%	Males	%	Females	%
Bifurcation (PIB and LCXB)	113	94.2	70	89.7	43	82.7
Trifurcation (PIB, LCXB and LDB)	7	5.8	3	10.3	4	17.3
Total	120	100	73	100	47	100

Table 2 – End of paraconal interventricular branch in homonym groove, cardiac apex and posterior surface, by gender.

	Total sample	%	Males	%	Females	%
Inferior third	38	31.2	23	32.9	15	30
Cardiac apex	79	65.8	45	64.3	34	68
Posterior surface	3	3	2	2.8	1	2
Total	120	100	70	100	50	100

Table 3 – End of the first left anterior ventricular branch (LAVB) of paraconal interventricular branch (PIB) on the obtuse side of the heart, by gender.

	Total sample	%	Males	%	Females	%
Upper third	64	61.5	54	71.1	10	35.7
Middle third	40	38.5	22	28.9	18	64.3
Total	104	100	76	100	28	100

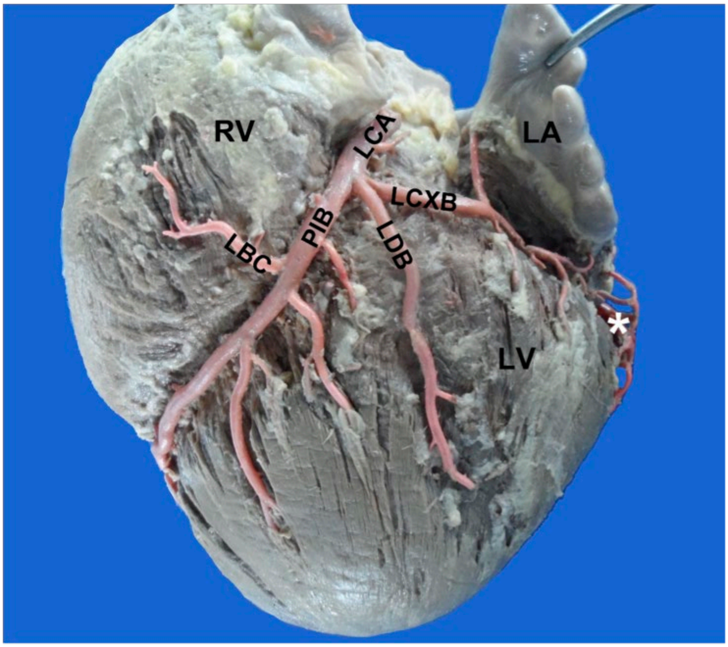

Figure 1 – Anterior view of the heart. LA: left atrium. LV: left ventricle. RV: right ventricle. LCA: left coronary artery PIB: paraconal Interventricular branch. LCXB: left circumflex branch. LDB: left diagonal branch. LBC: left branch cone. (*): right circumflex branch.

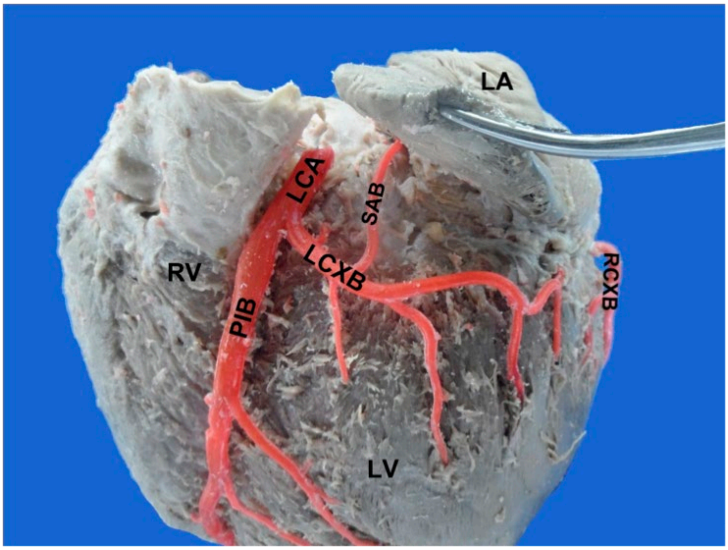

Figure 2 – Anterior view of the heart. LA: left atrium. LV: left ventricle. RV: right ventricle. LCA: left coronary artery. PIB: paraconal interventricular branch. LCXB: left circumflex branch. SAB: sino atrial branch. RCXB: right circumflex branch.

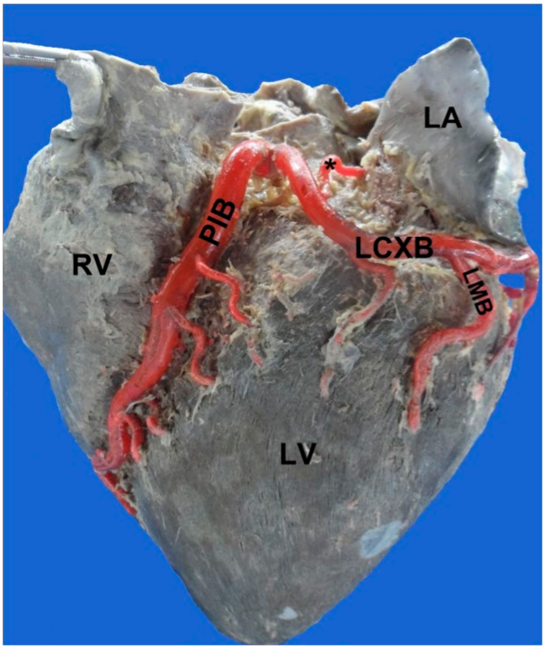

Figure 3 – Anterior view of the heart. LA: left atrium. LV: left ventricle. RV: right ventricle. PIB: paraconal Interventricular branch. LCXB: left circumflex branch. LMB: left marginal branch. (*) sino atrial branch

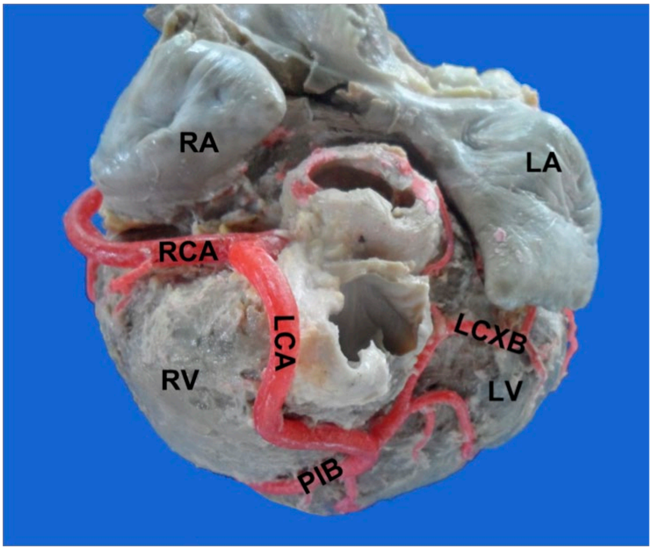

Figure 4 – Top view of the heart. Heart with single coronary artery, which originates the RCA and LCA. RA: right atrium. LA: left atrium. RV: right ventricle. LV: left ventricle. RCA: right coronary artery. LCA: left coronary artery. PIB: paraconal interventricular branch. LCXB: left circumflex branch.

The paraconal interventricular branch ended at the apex in 79 cases (65.8%), with no statistically significant differences being found between males and females (p=0.21) (Table 2). Its proximal diameter was 5.62 ± 1.97 mm; middle diameter: 4.04 ± 1.43 and distal diameter 2.23 ± 0.94 mm. This branch exhibited on average 3.2 ± 1.56 right ventricular branches and 5.25 ± 1.8 left ventricular branches (Fig. 1).

The first left anterior ventricular branch of the paraconal interventricular branch was found in 104 hearts (87.7%) being 2.44 ± 0.64 mm in diameter, and 40.18 ± 18.13 mm in length. The distance between its origin and the left coronary ostium was 46.29 ± 12.05 mm. This branch ended with greater frequency (61.5%) at the upper third of the obtuse margin of the heart (Table 3. Fig. 1).

The left circumflex branch was short and ended as left marginal branch in 55 samples (45.8%), at the posterior aspect of the left ventricle in 43 specimens (35.8%), at the level of the crux cordis in 2 hearts (1.7%), whereas it ended at the anterior aspect of the left ventricle in 20 cases (16.7%). Its proximal, middle and distal diameters were 4.05 ± 1.49 mm, 3.05 ± 1.09 mm and 2.14 ± 0.71 mm, respectively. The proximal diameters of the paraconal interventricular branch and the left circumflex branch showed no statistically significant differences (p=0.25). The sinoatrial node branch originated from the left circumflex branch in 100% of the cases, and the distance between its origin and the left coronary ostium was 21.7 ± 8.11 mm. Its mean diameter was 2.05 ± 0.81 mm (Fig. 2).

A left circumflex branch was found in 92 hearts (76.7%), ending at the upper third of the obtuse margin of the heart in 72 specimens (60%), whereas it ended at the middle third in 20 cases (40%). Its proximal diameter was 3.91 ± 15.01 mm, and its distal diameter was 1.63 ± 0.54 mm. This branch was 41.2 ± 14.1 mm in length, and the distance from its ending point to the apex was 97.9 ± 23.1 mm (Fig. 3). No myocardial bridges were found in the samples analyzed.

The presence of a single coronary artery bifurcating in RCA and LCA was observed. The LCA was projected onto the conus arteriosus and at the level of the anterior surface of the origin of the trunk of the pulmonary artery it was bifurcated in paraconal interventricular branch and left circumflex branch, both of which adopted a normal course. The RCA projected onto the coronary sulcus and near the crux cordis it bifurcated in the subsinusal interventricular branch and the right circumflex branch (Fig. 4).

Discussion

The information on the morphological characteristics of the LCA in the horse is limited. Therefore, the findings of the present study significantly enrich the information reported in previous studies on this subject, and allows for making comparisons within the context of comparative anatomy with humans, pigs, donkeys, and other animal species (Cave, 1936; Rodriguez et al., 1961; Schummer et al., 1981; Thtiroff et al., 1984; Ozgel et al., 2004; Ballesteros and Ramirez, 2008; Sahni et al., 2008; Yuan et al., 2009)

The diameter of the LCA in donkeys is 0.9-1 mm (Ozgel et al., 2004; Ozgel and Dursun, 2005). This differs from our findings in horses with much greater figures (6.76 mm). A division of the LCA into paraconal interventricular branch and left circumflex branch has been reported in 100% of the cases in donkeys, horses, camels, and elephants (Cave, 1936; Schummer et al., 1981; Ghazi and Tadjalli, 1993; Ozgel et al., 2004; Ozgel and Dursun, 2005; Yuan et al., 2009). This differs from our study, which found a trifurcation variant with the presence of an intermediate left diagonal branch in 5.8% of the cases. Some studies in pigs have reported the LCA branching in all samples (Crick et al., 1998; Sahni et al., 2008), while other series report trifurcation within a range of 20-21% (Jordão et al., 1999; Gómez and Ballesteros, 2014). In humans a bifurcation of the LCA has been described in 40-70% of the cases, trifurcation in 9-55%, and tetrafurcation in 5-7% of the hearts studied (Ortale et al., 2005; Ballesteros and Ramirez, 2008).

The paraconal interventricular branch has been reported as being 0.6 mm in diameter in donkeys (Ozgel et al., 2004; Ozgel and Dursun, 2005), in contrast with a much greater figure in our investigation (5.62 mm). It has also been described as ending at the heart apex, as in elephants, pigs, and humans, consistent with our series (65.8%) (Cave, 1936; Ozgel et al., 2004; Ozgel and Dursun, 2005; Ballesteros and Ramirez, 2008; Sahni et al., 2008; Gómez and Ballesteros, 2014).

In pigs it has been reported that the left diagonal branch ends at the lower third of the obtuse margin of the heart (Gómez and Ballesteros, 2014), whereas other studies in this species have described that this structure ends primarily at the upper third, as occurs in humans (Jordão et al., 1999; Ortale et al., 2005).

The caliber of the paraconal interventricular branch found in our study (5.62 mm) is much greater than the 0.6 mm reported in donkeys (Ozgel et al., 2004; Ozgel and Dursun, 2005). These differences could be explained by the methodology of measurement, and the sizes of the samples and the specimens evaluated. The paraconal interventricular branch ending at the cardiac apex in 65.8% of the cases in our series is consistent with what has been reported in elephants, pigs, and humans (Cave, 1936; Ozgel et al., 2004; Ozgel and Dursun, 2005; Ballesteros and Ramirez, 2008; Sahni et al., 2008; Gómez and Ballesteros, 2014).

The presence of a left anterior ventricular branch has been reported in 84-90% of the cases in pigs and humans, a figure consistent with our findings (Ortale et al., 2005; Gómez and Ballesteros, 2014). However, while in pigs and humans it is reported as ending at the middle third of the left ventricle, our study found it to be shorter in length, and ending primarily at the upper third. In donkeys, this branch is 0.3 mm in caliber and has a caudal-ventral direction (Ozgel et al., 2004).

In horses, camels and pigs, the left branch cone has not been found to anastomose with its contralateral branch (Schummer et al., 1981; Ghazi and Tadjalli, 1993; Sahni et al., 2008; Gómez and Ballesteros, 2014) as noted in our work, unlike bovines, where the anastomosis of these two branches has been described (Schummer et al., 1981). Ozgel et al., 2004 described the left circumflex branch as ending primarily as left marginal branch, which is consistent with our findings. In camels, pigs, and humans it has been reported as ending primarily at the posterior aspect of the left ventricle (Crick et al., 1998; Ballesteros and Ramirez, 2008; Sahni et al., 2008; Yuan et al., 2009; Gómez and Ballesteros, 2014) and in elephants at the interventricular paraconal sulcus (Cave, 1936).

Some studies in pigs report the sinoatrial node branch as originating from the RCA in 100% of cases (Crick et al., 1998; Gómez and Ballesteros, 2013), but Sahni et al., (2008) reported this branch as emerging from the RCA in 70% of the samples, and from the left circumflex branch in 30%. In humans, the sinoatrial node branch has been reported as originating from the RCA in 50-79% of the cases, from the left circumflex branch in 30-45%, and from both arteries in 3-7% (Pejkovic et al., 2008; Saremi et al., 2008; Ramanathan et al., 2009). Our study does not coincide with any previous report on the evaluated species and on humans, since we observed this branch emerging from the left circumflex branch in 100% of the cases.

In donkeys, pigs, and humans the left marginal branch has been reported as ending at the upper third of the obtuse margin of heart, which is consistent with our work (Ballesteros and Ramirez, 2008; Gómez and Ballesteros, 2014). In pigs (Gómez and Ballesteros, 2014), this finding has been reported with an incidence (87.9%) slightly higher than that found in our series.

Our study did not find any myocardial bridges at the level of the LCA and its branches. This morphological feature has not been evaluated in previous studies (Rodriguez et al., 1961; Rawlings, 1977; Sisson et al., 1995). Vascular segments embedded in the myocardium have been described in pigs and camels with an incidence of 24-86%, located mainly at the middle segment of the RIS (Kosiński et al., 2010; Babiker and Taha, 2013; Gómez and Ballesteros, 2015). In humans, unlike the above-mentioned species, myocardial bridges have been reported affecting mainly the anterior interventricular branch and the diagonal branch within a wide range 23-88% (Sahni and Jit, 1991; Lima et al., 2002; Ballesteros et al., 2009). In humans, it has been postulated that MB constitute the anatomic substratum that, together with other vascular factors, can cause cardiac arrhythmias, angina, and even sudden death (Gow, 2002; Rozenberg et al., 2004). Since no myocardial bridges are found in horses, no mention should be made of this possibility within the context of the pathophysiology of the cardiovascular system.

Conclusions

The sinoatrial node branch originated from the left circumflex branch of the LCA in 100% of cases, which differs from what has been observed in other species. Trifurcation of the LCA was observed, which differs from what has been found in horses and other animal species.

The left circumflex branch was predominantly short, and was found to end at the obtuse edge of the heart as left marginal branch, so the posterior wall of the left ventricle was irrigated by branches from the right coronary artery. No myocardial bridges were observed in the LCA or its branches. The morphology and biometry of the LCA and its branches found in this study are very similar to those observed in the human heart, which allows for ratifying the use of the equine model in procedural and hemodynamic applications.

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References

Ballesteros L.E., Ramirez L.M. (2008). Morphological expression of the left coronary artery: a direct anatomical study. Folia. Morphol. (Warsz) 67: 135-142.

Ballesteros L.E., Ramirez L.M., Saldarriaga B. (2009). Morphological description and clinical implications of myocardial bridges: an anatomical study in Colombians. Arq. Bras. Cardiol. 92: 242–248.

Cave A.J. (1936). On the cardiac arteries of the asiatic elephant. J. Anat. 71: 124-127.

Crick S.J., Sheppard M.N., Ho S.Y., Gebstein L., Anderson R.H. (1998). Anatomy of the pig heart: comparisons with normal human cardiac structure. J. Anat. 193: 105-119.

Ghazi S.R., Tadjalli M. (1993). Coronary arterial anatomy of the one-humped camel (Camelus dromedarius). Vet. Res. Commun. 7: 163-170.

Gómez F.A., Ballesteros L.E. (2013). Anatomic study of the right coronary artery in pigs. Feature review in comparison with the human artery. Int. J. Morphol. 31: 1289-1296.

Gómez F.A., Ballesteros L.E. (2014). Morphologic expression of the left coronary artery in pigs. An approach in relation to human heart. Rev. Bras. Cir. Cardiovasc. 29: 214-220.

Gow R.M. (2002). Myocardial bridging: does it cause sudden death? Card. Electrophysio. Rev. 6: 112–114.

Jordão M.T., Bertolini S.M., Areas Junior J.H. (1999). Anatomic study of the diagonal arteries in hearts of pigs. Rev. Chil. Anat. 17: 75-79.

Lima V.J., Cavalcanti J.S., Tashiro T. (2002). Myocardial bridges and their relationship to the anterior interventricular branch of the left coronary artery. Arq. Bras. Cardiol. 79: 215-222.

Ortale J.R., Meciano Filho J., Paccola A.M., Leal J.G.P.G., Scaranari C.A. Anatomia dos ramos lateral, diagonal e ântero-superior no ventrículo esquerdo do coração humano. Rev. Bras. Cir. Cardiovasc. 20: 149-158.

Ozgel O., Haligur A., Dursun N., Karakurum E. (2004). The macroanatomy of coronary arteries in donkeys (Equus asinus L.). Anat. Histol. Embryol. 33: 278-283.

Ozgel O., Dursun N. (2005). The arterial vascularization of septum interventriculare in donkeys (Equs asinus L). Anat. Histol. Embryol. 34: 80-84.

Pejkovic B., Krajnc I., Anderhuber F. (2008). Anatomical aspects of the arterial blood supply to the sinoatrial and atrioventricular nodes of the human heart. J. Int. Med. Res. 36 (4): 691-698.

Ramanathan L., Shetty P., Nayak S.R. (2009). Origin of the sinoatrial and atrioventricular nodal arteries in South Indians: an angiographic study. Arq. Bras. Cardiol. 92 (5): 314-319, 330-335, 342-348.

Rawlings C.A. (1977). Coronary arterial anatomy of the small pony. Am. J. Vet. Res. 38: 1031-1035.

Rodriguez F.L., Robbins S.L., Banasiewicz M. (1961). The descending septal artery in human, porcine, equine, ovine, bovine, and canine hearts: A postmortem angiographic study. Am. Heart. J. 62: 247-259.

Rozenberg V.D., Nepomnyashchikh L.M. (2004). Pathomorphology and pathogenic role of myocardial bridges in sudden cardiac death. Bull. Exp. Biol Med. 138: 87-92.

Rychter K., Salanitri J., Edelman R.R. (2006). Multifocal coronary artery myocardial bridging involving the right coronary and left anterior descending arteries detected by ECG-gated 64 slice multidetector CT coronary angiography. Int. J. Cardiovasc. Imaging. 22: 713-717.

Sahni D., Jit I. (1991). Incidence of myocardial bridges in northwest Indians. Indian. Heart. J. 43: 431-436.

Sahni D., Kaur G.D., Jit H. (2008). Anatomy and distribution of coronary arteries in pig in comparison with man. Indian J. Med. Res. 127: 564-570.

Saremi F., Channual S., Abolhoda A. (2008). MDCT of the S-shaped sinoatrial node artery. AJR. Am. J. Roentgenol. 190:1569-1575.

Schummer A., Wilkens H., Vollmerhaus B. (1981). The Anatomy of the Domestic Animals. Vol 3. Springer Verlag. New York.

Sisson S., Grossman J., Getty R. (1995). Anatomía de los Animales Domésticos. Tomo II. 5th edn. Editorial Salvat. Ciudad de México.

Thtiroff J.W., Hort W., Lichti H. (1984). Diameter of coronary arteries in 36 species of mammalian from mouse to giraffe. Basic. Res. Cardiol. 179: 199-206.

Yuan G., Jinghong M., Wenling Y., Zhongtian B. (2009). Macroanatomy of coronary arteries in Bactrian camel (Camelus bactrianus). Vet. Res. Commun. 33: 367–377.