

Coronary Irrigation in *Puma concolor* (Carnivora: Felidae)

Irrigación Coronaria en *Puma concolor* (Carnivora: Felidae)

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SUMMARY: This study described the anatomy of the coronary arteries and their main branches in *Puma concolor*. The hearts of six individuals of *Puma concolor*, were analyzed. The A. coronaria sinistra formed the ramus interventricularis paraconalis and the ramus circumflexus. A ramus septal was formed close to the origin of the ramus interventricularis paraconalis and yielded from six to eight ventricular branches. The circumflex branch originated from two to five atrial branches and from three to seven ventricular branches. The right coronary artery formed two to six atrial branches, and four to nine ventricular branches. In half of the individuals, an accessory coronary artery was identified as the first branch of the right coronary artery. In all individuals, the subsinusal interventricular branch originated in the right coronary artery. It could be inferred that coronary circulation in *Puma concolor* is balanced, as each coronary artery yielded an interventricular branch and there was no significant difference in the total number of branches that originated from each coronary artery. These findings are different from the descriptions of most carnivore species, and may aid a better understanding of the phylogenetic relationships and synapomorphies of carnivore coronary circulation, especially in the Felidae family.

KEY WORDS: Cardiovascular system; Carnivores; Coronary dominance; Cougar.

INTRODUCTION

The *Puma concolor* (Linnaeus, 1771), also known as puma, mountain lion, red tiger, deer tiger, or cougar (Cheida & Santos, 2010), is the second largest felid in the Americas and the most widely spread in the continent, ranging from Canada to Uruguay (Cheida & Santos; Hunter, 2011). It is a fast animal (reaching 60 km/h) of solitary and nocturnal habits. It is able to jump up to 5 m, besides climbing and swimming easily (Cheida & Santos; Hunter). In the search for food, it may cover more than 40 km in a single night (Cheida & Santos); males may cover even greater distances (Hunter). It hunts medium-sized mammals, such as peccaries, deer, spotted pacas, and coatis, having an important role in the ecosystems (Cheida & Santos; Hunter). The cougar lives from nine to sixteen years in natural conditions, and up to twenty years in captivity (Cheida & Santos; Hunter).

Coronary arteries receive about 10 % of the volume of blood ejected during the systole, and are essential for the cardiac function (Shummer *et al.*, 1981). This functional significance has led to several detailed studies on the right and left coronary arteries and their main branches in

mammals (Monfared *et al.*, 2013; Borelli, 2014). Large felids make considerable physical effort to find and capture their preys. Therefore, blood supply to the myocardium is one of the bases to its survival. Despite this important fact, studies on the coronary anatomy of wild carnivores are scarce (Marques, 1962; Perez & Lima, 2007; Souza *et al.*, 2015a; Souza *et al.*, 2015b, Souza *et al.*, 2015c).

Since the first anatomic descriptions of the coronary arteries, it was established that mammals may have one of three types of coronary circulation: right, left, or balanced (bilateral) (Banchi, 1904). This classification is determined by the contribution of each coronary artery in the irrigation of the ventricles and the formation of the paraconal and subsinusal interventricular branches (Shummer *et al.*). When the left coronary artery supplies blood to both interventricular branches, it is classified as left dominance. Right dominance occurs when both interventricular branches receive blood from the right artery. When the left coronary artery gives rise to the paraconal branch, and the right artery to the subsinusal branch, circulation is called balanced.

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Among domestic mammals, pigs and horses show balanced type coronary circulation, while dogs and ruminants show left dominance (Shummer *et al.*; Biasi *et al.*, 2013; Correia-Oliveira *et al.*, 2013). In domestic cats, most of the studies point out to left dominance, but the prevalence of right dominance and balanced circulation is also debated (Shummer *et al.*; Borelli)

Given the ecological importance of the cougar, the functional significance of the coronary circulation, the scarcity of descriptions related to wild felids, and the controversial coronary dominance in felids, the objective of this study was to describe the anatomy of the coronary arteries and their main branches in *P. concolor*.

MATERIAL AND METHOD

Six hearts of *Puma concolor* were analyzed. The organs came from three males and three females. One the males was a young animal (about two months of age). All individuals were found dead on the highways of the state of Minas Gerais (cooperation agreement no. 002/2011 between Universidade Federal de Uberlândia and the IBAMA).

Animals were identified and placed in right lateral decubitus. After that, the thorax was opened on the sixth intercostal space and dissected to show the thoracic aorta, which was cannulated. After that, the arterial system was perfused with NaCl solution 0.9 %, and fixed with formaldehyde solution 10 %. Latex was injected in three of the animals (Petrolatex S65® solution Duque de Caxias Refinery, Petrobras, Duque de Caxias, RJ) to fill up the arterial system. The bodies were immersed in formaldehyde 10 % in 500-L low density polyethylene boxes for the fixation process to be complete. After 7 days of fixation, the thoracic cavity was opened by means of median sternotomy and, after thorax structures were recognized, the heart was removed along with the large vessels.

After that, the pericardial sac was removed and the coronary arteries and their main branches were visible to be dissected with the aid of tweezers and a binocular stereoscopic microscope (Leica EZ4®). Data was recorded with schematic drawing and photomacrographs (Nikon Coolpix® L820 camera, 16MP). Nomenclature adopted was based on the Nomina Anatomica Veterinaria (ICVGAN, 2012).

Data on the number of ventricular branches in the interventricular paraconal branch, septal branches, atrial and ventricular branches of the circumflex branch, origin of the

left and right marginal arteries, number of ventricular branches of the subsinusal branch, atrial and ventricular branches of the right coronary artery, and presence or absence of the accessory coronary artery were recorded on BioEstat® spreadsheets. Comparisons between the mean number of branches originated in the left and right coronary artery, between males and females, and between the adults individuals and the young one were carried out using the unpaired t test for independent samples, with $p < 0.05$. Linear correlation was also determined between the number of atrial and ventricular branches of the arteries and the other branches listed above.

RESULTS

The six individuals showed both the right and left coronary arteries. The left coronary artery originated in the left sinus of the aortic bulb, followed a short path and bifurcated to yield the paraconal interventricular and circumflex branches as shown in Figure 1.

The paraconal interventricular branch followed the corresponding groove to the apex of the heart in five individuals (three females and two males) (83.3 %), always forming a septal branch near its origin. In one male individual (16.7 %), the paraconal interventricular branch ended in a pre-apical position. From the paraconal interventricular branch, six to eight ventricular branches were formed (7.10 ± 0.98). The circumflex branch was located on the coronary groove, originating two to five atrial branches (3.00 ± 1.55), and from three to seven ventricular branches (4.50 ± 1.97).

The right coronary artery appeared on the right sinus of the aortic bulb, followed the coronary groove yielding from two to six atrial branches (3.50 ± 1.37) and between four to nine ventricular branches (5.83 ± 1.94). In two females and one male (50.0 %), an accessory right coronary artery was observed as the first branch of the right coronary artery taking the coronary groove towards the conus arteriosus.

In all individuals, the right coronary artery originated the subsinusal interventricular branch, which was invariably placed in homonymous groove, and ended in the apex of the heart in four individuals (two males and two females) (66.6 %). In one male individual (16.7 %), the subsinusal branch passed by the apex and ended on the left ventricular face of the heart; in one female (16.7 %), it did not reach the apex. On its path, this branch originated between one to seven ventricular branches (4.16 ± 2.13).

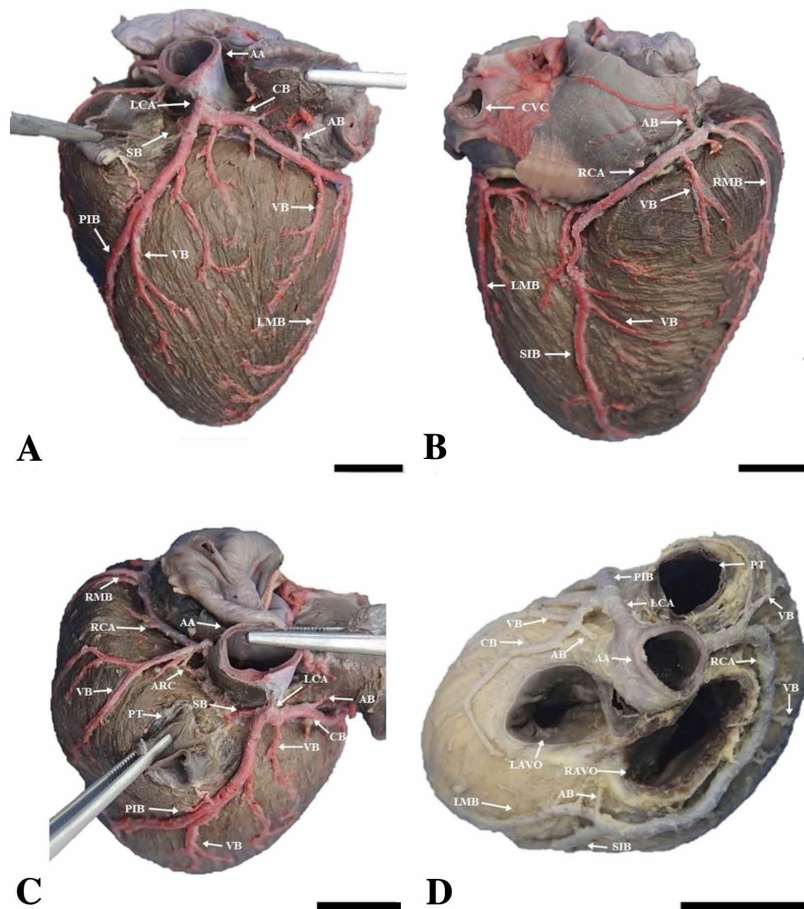


Fig. 1. Photomicrographs of the heart of an adult male *Puma concolor* individual, left (A) and right (B) face; left dorsolateral view (C), and dorsal view of the base of the heart of an adult female individual after removal of the auricles (D). Aorta artery (AA); pulmonary trunk (PT); left atrioventricular ostium (LAVO); right atrioventricular ostium (RAVO); left coronary artery (LCA); paraconal interventricular branch (PIB); septal branch (SB); ventricular branches (VB); circumflex branch of left coronary artery (CB); atrial branches (AB); left marginal branch (LMB); right coronary artery (RCA); subsinuosal interventricular branch (SIB); right marginal branch (RMB). The right marginal branch (RMB) was absent in the female individual (D), Bar: 2 cm.

The left marginal artery, located on the left ventricular edge, originated from the circumflex branch of the coronary artery in two individuals, one male and one female (33.3 %). In three individuals, two males and one female (50 %), it originated in the right coronary artery after forming the subsinusal interventricular branch. In a female individual (16.7 %), the left marginal artery was not found.

The right marginal artery was located on the edge of the right ventricle, and was observed in five individuals (three males and two females) (83.3 %), originating from the right

coronary artery. In one female individual (16.7 %), this artery was not observed.

When the total number of branches was counted (atrial, ventricular, interventricular, septal, marginal) as originating from the left and right coronary artery, the former originated, in average, 18.00 ± 2.89 branches, whereas the latter, 16.17 ± 2.71 branches, with no significant difference between the average number of branches originating from each of them ($p = 0.29$).

The left coronary artery originated 11.70 ± 1.75 ventricular branches, whereas the right coronary artery yielded 10.00 ± 2.28 branches, with no significant difference between the average number of ventricular branches originating from each coronary artery ($p = 0.18$). When atrial branches were considered, the left coronary artery yielded 3.00 ± 1.55 branches and the right one, 3.50 ± 1.38 branches, with no significant difference between them ($p = 0.56$).

Comparison between the sexes related to the number of atrial ($p = 0.56$), ventricular branches ($p = 1.0$), and total number of atrial and ventricular branches ($p = 0.82$) did not show significant differences.

The sum of atrial and ventricular branches in the young individual was lower (21 branches) that the average in adults (29.6 branches), with no significant difference ($p = 0.13$).

There was a positive linear correlation between the number of atrial branches from the circumflex branch and the ventricular branches originating in the paraconal interventricular branch ($r = 0.85$). The same occurred with the number of ventricular branches originating in the circumflex branch and the number of right ventricular branches originating in the right coronary artery ($r = 0.81$). There was a negative correlation between the number of ventricular branches originating in the paraconal interventricular branch and in the circumflex branch ($r = -0.46$).

DISCUSSION

Coronary circulation of *Puma concolor* may be considered balanced, given two criteria. First, each coronary artery originated one interventricular branch, that is, the left coronary artery originated the paraconal interventricular branch and the right one, the subsinusal interventricular branch. The second criterion takes into account the total number of branches originating from each coronary artery: although the left coronary artery originated 18 branches and the right one originated 16, in average, there was no significant difference between them.

The balanced pattern is cited in textbooks of veterinary anatomy in horses and pigs (Shummer *et al.*), and in other mammal, New Zealand rabbits (Correia-Oliveira *et al.*, 2014a). In carnivores, it was reported in 33.3 % of the domestic cats (n = 30) analyzed by Biasi *et al.* (2012); and in only 18.3 % of the domestic cats (n = 60) dissected by Borelli.

In fact, the most common coronary pattern in carnivores is left dominance. In the Canidae family, it seems like a rule: it was described in all domestic dogs dissected by Moore (1930), Oliveira *et al.* (2011), and Biasi *et al.*; in a fox species (probably *Vulpes vulpes* (Linnaeus, 1758)) described by Hadziselimovic *et al.* (1974); and in *Cerdocyon thous* (Linnaeus, 1766) described by Souza *et al.*, (2015b).

The only description of balanced coronary circulation in domestic dogs was reported by Andretto *et al.* (1973), who cited the occurrence of balanced circulation in only 6.4 % of the 250 domestic dogs analyzed by them. Left dominance was also observed in the Procyonidae family in the species *Nasua nasua* (Linnaeus, 1766) (Souza *et al.*, 2015a) and *Procyon cancrivorus* (G. Cuvier, 1798) (Souza *et al.*, 2015c).

In the Felidae family, left dominance was observed in twenty wild cats (possibly *Felis silvestris* (Schreber, 1777)) (Hadziselimovic *et al.*); in one *Panthera leo* (Linnaeus, 1758) (Marques); and in one *Panthera tigris* (Linnaeus, 1758) (Perez & Lima). In domestic cats, both Biasi *et al.* and Borelli found left coronary dominance in 63.3 % of the individuals. Therefore, according to the literature, the present study is the first to report a felid species in which all the individuals showed balanced coronary circulation.

Maybe left dominance is a characteristic of the Pantherinae subfamily, whereas the Felinae subfamily may present both balanced circulation (such as in *P. concolor*

and part of the domestic cats), left dominance (in most of the domestic and wild felids), or right dominance (marginal number of the domestic cats). This hypothesis may be a phylogenetic issue to be clarified by studies involving more individuals and a greater variety of species.

The fact that the male *P. concolor* individuals cover distances that are considerably greater than females (Hunter) could lead to the inference that some coronary dominance characteristic may exist, or mainly, that the number of atrial or ventricular branches could be different for males and females, once the functional cardiovascular demand seems to be different. However, this variation was not found in the present study. The absence of signs of sexual dimorphism in coronary circulation was also reported by Moura Junior *et al.* (2008) in pigs; Biasi *et al.*, and Borelli in domestic cats; Biasi *et al.* in domestic dogs; and Correia-Oliveira *et al.* (2014a) in New Zealand rabbits.

Moore did not find differences when comparing the coronary circulation in clearly young and adult dogs. This finding was also observed in the young *P. concolor* individual and the adult ones in relation to coronary dominance and the number of atrial and ventricular branches.

In *P. concolor*, the number of ventricular branches in the paraconal interventricular branch ranged from six to eight (average of 7.10 branches). In domestic dogs, the number of branches is usually twelve (Correia-Oliveira *et al.*, 2014b), or ranges between five and fourteen (average of 9.9 branches), according to Oliveira *et al.* In domestic cats, it ranges from three to nine (average of 5.7 branches), according to Monfared *et al.* In domestic pigs, it ranges from 16 to 25 (average of 21.8 branches), according to Moura Junior *et al.*; and in cattle, the average is 12.7 branches, according to Correia-Oliveira *et al.* (2014b).

While in *P. concolor* the paraconal interventricular branch was found ending in the apex of the heart in 83.3 % of the individuals, Oliveira *et al.* reported this location in a little more than half of the dogs; Monfared *et al.*, in 48.7 % of domestic cats; and Moura Junior *et al.*, in only 43.3 % of pig hearts.

The septal branch originating from the paraconal interventricular branch in all *P. concolor* individuals in the present study follows the pattern described in 60 % of the twenty domestic dogs analyzed by Noestelthaller *et al.* (2007); and 62.5 % of the eight *C. thous* individuals dissected by Souza *et al.* (2015b). The other possibilities describe the septal branch originating in the left coronary artery, in the aorta, or in the circumflex branch (Noestelthaller *et al.*).

The number of atrial branches originating from the circumflex branch was described ranging from one to six (average of 4.1 branches) in the domestic dog (Oliveira *et al.*), whereas in *P. concolor*, it ranged from one to five (average of 3.0 branches).

The number of ventricular branches originating in the circumflex branch ranges from two to six in the domestic dog, as described by Pianetto (1939); or from three to twelve (average of 6 branches), as described by Oliveira *et al.* In pigs, from four to thirteen (average of 8.4 branches), as described by Moura Junior *et al.*, and in average 3.3 branches in cattle, as described by Correia-Oliveira *et al.* (2014b). In *P. concolor*, it ranged from three to seven (average of 4.5 branches).

The left marginal artery was found in five (83.3 %) of the *P. concolor* individuals. It was found in 100 % of the hearts of thirty domestic dogs analyzed by Oliveira *et al.*; in 100 % of the 30 Landrace pigs analyzed by Moura Junior *et al.*; in 89.4 % of the 15 feline hearts analyzed by Monfared *et al.* In all these species, the left marginal artery was reported as originating from the circumflex branch of the left coronary artery, which was observed in only 33.3 % of the *P. concolor* individuals. In 50 % of the *P. concolor* individuals, the right coronary artery originated the left marginal artery after yielding the subsinusal branch.

While Evans & De Lahunta (2013) described only one or two atrial branches of the right coronary artery in domestic dogs; Oliveira *et al.* described between two to nine (average of 4.2 branches); Monfared *et al.* reported from zero to three (average of 1.3 branches) in domestic cats; and Moura Junior *et al.* described between four to nine branches (average of 6.7 branches) in pigs. In *P. concolor*, two to six branches were found (average of 3.5 branches).

The number of direct ventricular branches originating from the right coronary artery in *P. concolor* was similar to that described by Pianetto in 31 domestic dogs, that is, from four to nine branches (average of 5.8 branches). However, this number was lower than that described by Oliveira *et al.*, from six to twenty branches (average of 6.5 branches) in domestic dogs; by Monfared *et al.*, from three to eight (average of 4.7 branches) in domestic cats; and by Moura Junior *et al.*, from 12 to 21 branches (average of 9.0 branches) in pigs.

The right accessory coronary artery, although originating from the right coronary artery and not from the right sinus of the aortic bulb, was recognized in three *P. concolor* individuals (50.0 %). The artery followed the

coronary groove and spread in the conus arteriosus region, as mentioned by Evans & De Lahunta. It was also described in only 20 % of the hearts of 63 domestic dogs analyzed by Moore; in two hearts of *Nasua nasua* by Souza *et al.* (2015a); and in four (50 %) of eight *Cerdocyon thous* hearts by Souza *et al.* (2015b).

The number of ventricular branches of the subsinusal branch ranges from 8 to 10 in the domestic dog, according to Evans & De Lahunta, or between one and 8 (average of 4.1 branches), according to Oliveira *et al.* In domestic cats, one to 8 branches were reported (average of 3.6 branches) by Monfared *et al.* In pigs, Moura Junior *et al.* reported from 9 to 22 branches (average of 15.7 branches), and Correia-Oliveira *et al.* (2014b) determined an average of 8.5 branches in cattle. In *P. concolor*, it ranged from one to 7 (average of 4.16 branches).

The interventricular subsinusal branch ended in the apex of the heart in 66.6 % of the *P. concolor* individuals. This arrangement was recorded in only 21 % domestic cats analyzed by Monfared *et al.*; in 20 % of the dogs analyzed by Oliveira *et al.*; and in 20 % of the pigs studied by Moura Junior *et al.* In these three species, the most common presentation of the interventricular subsinusal branch was ending before reaching the apex, an arrangement that was observed in only one *P. concolor* individual.

The right marginal artery was recognized in five (83.3 %) *P. concolor* hearts as a branch of the right coronary artery. However, it was reported in 100 % of the pigs dissected by Moura Junior *et al.*, and in 98.7 % of the cat hearts analyzed by Monfared *et al.*

In summary, the left coronary artery originated the paraconal and circumflex interventricular branches, whereas the right coronary artery originated the subsinusal interventricular branch. Coronary circulation in *P. concolor* was balanced type, different from what has been described for most carnivorous species. There were no signs of sexual dimorphism in the coronary circulation of *P. concolor*. Studies with a greater number of species may clarify phylogenetic relationships and synapomorphies related to the coronary circulation of the carnivores, especially in the Felidae family.

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VIOTTO-SOUZA, W.; SOUZA JUNIOR, P. ; CARVALHO, A. D.; ABIDU-FIGUEIREDO, M. & SANTOS, A. L. Q. Irrigación Coronaria en *Puma concolor* (Carnivora: Felidae). *Int. J. Morphol.*, 35(3):925-930, 2017.

RESUMEN: En este estudio se describió la anatomía de las arterias coronarias, y sus principales ramas, en el *Puma concolor*. Se analizaron los corazones de seis especímenes de *Puma concolor*. La arteria coronaria izquierda formó la rama interventricular paraconal y la rama circunfleja. Una rama septal se formó cerca del origen de la rama paraconal y otorgó de seis a ocho ramas ventriculares. La rama circunfleja originó de dos a cinco ramas atriales y de tres a siete ramas ventriculares. La arteria coronaria derecha originó de dos a seis ramas atriales y de cuatro a nueve ramas ventriculares. En la mitad de los especímenes, se identificó una arteria coronaria accesoria como la primera rama de la arteria coronaria derecha. En todos los individuos, la rama interventricular subsinusal se originó en la arteria coronaria derecha. Se podría inferir que la circulación coronaria en el *Puma concolor* es equilibrada, ya que cada arteria coronaria produce una rama interventricular y no hay diferencia significativa en el número total de ramas que se originan de cada arteria coronaria. Estos hallazgos son diferentes de las descripciones de la mayoría de las especies carnívoras y pueden ayudar a una mejor comprensión de las relaciones filogenéticas y de las sinapomorfias de la circulación de los carnívoros, especialmente en la familia Felidae.

PALABRAS CLAVE: Sistema cardiovascular; Carnívoros; Dominancia coronaria; León bayo.

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