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# RIGHT CORONARY ARTERY IN CERCOPITHECUS AETHIOPS SABEUS

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*The investigation was carried out on 55 monkey (Cercopithecus aethiops) hearts by stereomicroscopic dissection and measurements. Latex injected specimens and corrosion cast showed that, like in humans, the RCA orifice was usually situated in the middle part of the right aortic sinus, slightly above the free edge of the valve leaflet (82.3%). The long RCA type was the most frequent finding (70.9%), as in humans. Among them, in 7.2% RCA extends its route via the coronary groove, and terminats as the posterior left ventricular branch. In 23.6% RCA terminated as posterior right ventricular branch (short type), and occasionally, in 5.5% RCA terminated as right marginal branch (extremely short type). The first branch of RCA very often was the conal artery (74.5%), what is similar to humans. The blood supply to the sinuatrial node more frequently (85.5%) was by a branch of RCA. Similar to the former, AV node artery most frequently arose from RCA (69.2%). The numbers of descending (rami marginales) RCA branches varied between 1-6, and their origin and distribution resembles the corresponding ones in humans. No statistically significant sexual differences in length and distribution pattern were present. This study shows that the anatomy of RCA or its branching patterns in monkey hearts are very similar to the humans.*

*Key words: right coronary artery, anatomy, distribution, non human primates*

## INTRODUCTION

Knowledge of the normal coronary anatomy and its variations and (or) anomalies is essential in making a choice of the appropriate experimental animal as a model in cardiovasclular studies. The term "normal coronary anatomy" refers to the habitually observed structures. The term "anomaly" is used for variations that occur in less then 1% of the general population (Angelini *et al*., 2002). Failure to distinguish between normal and anomalous structures may lead to misinterpretations. In this article we will describe the most prevalent variations of the right coronary artery (RCA) in CAs, which are those with a frequency over 1%.

The position of the coronary artery and its relation to the myocardium are limiting factors in animal selection. Researching coronary arteries distribution in different species of mammals, Polaček and Audrlicka 1961, concluded that those factors are determined by constitution of the animal and consecutive, heart size. As type A, they classified coronary vascular network where the main coronary arteries and their branches have an intramural route, as recorded in small mammals, such as small ruminants and rabbits; in type B of circulation, the coronary arteries were predominantly epicardially located, with partial intramural segments, as found in sheep, dogs and cats; coronary arteries in type C of circulation, occupied the epicardial (epimural) position exclusively, as described in big mammals as horses and cows. Other authors could not agree with Polaček and Audrlica that the arterial course depends on animal size (Berg, 1964a; Hadžiselimović *et al*., 1974). They describe it as more a phylogenic problem.

After studying coronary arterial vessels in human primates Chase and de Garis (1939), Hill (1977), de Lacerda and Hureau (1986), noticed that they have a typical route. They found that coronary arteries in chimpanzees take mainly the intramural route, while in gorillas and gibbons are predominantly epimurally located. This suggested a lack of fixed rules in the behaviour of coronary arteries in relation to the myocardium and supports the biogenetic principle. Studies of the coronary arteries distribution in non-human primates, conducted mainly on *Macaca fascicularis* and *Macaca radiata* monkeys indicated a predominantly subepicardial course (Buss *et al.*, 1982; Teofilovski *et al*., 1993), with short intramural portions. Such course being close to type B of Polaček and Audrlica' classification. This, as well as the distribution of coronary artery branches very similar to humans, suggested that these animals could be more suitable for investigations of the cardiovascular system compared with the model provided by the Syrian hamster commonly used for studies of congenital coronary artery anomalies. It has been reported (Sans-Coma *et al*., 1993) that the course of coronary arteries in the Syrian hamster is intramyocardial.

It is well known that the main coronary arteries and their branches in humans habitually follow an epicardial route. It has been recognized for over 200 years that these epicardial arteries may penetrate into the myocardium for limited segments. Considering subepicardial coronary arteries' location, and their intramural portions, coronary network in humans shows certain similarities to animal type B, according to the classification by Polaček and Audrlica'.

The purpose of this study was to obtain the data about the vascular pattern of the RCA and its branches in CAs, and to establish a model for a particular heart area supplied by RCA. Also, we wanted to make a comparison to human RCA area model, and to conclude if those animals have "the most human type" RCA vascular patern among mammals.

## MATERIALS AND METHODS

The present study was done on 55 CAs isolated hearts. Animals used in our study originated from East Africa (Kenya, Uganda and Tanzania), and were housed at Torlak Institute for Immunology and Virology in Belgrade in accordance

with the international guidelines on the ethical use of animals. The monkeys were of both sexes (35 females and 20 males), housed in pairs in a climate-controlled environment (temperature 27 C; 12-h light/dark circle) and fed *ad libitum*. The animals were deeply anaesthetized by intraperitoneal injection of sodium pentobarbital and sacrificed by exsanguination. After sacrification, coronary arteries were injected *in situ*, through the aortic arch. Under constant pressure of 18 kPa the following substances were injected: Latex and China ink gelatin solution (group A) for better visualization of blood vessels during micro dissection, and Symgal (methyl metacrylate, Galenika Beograd), for corrosion casts (group B). When the procedures were performed, hearts were removed from the thorax and immersed in 10% formalin solution (group A), or in NaOH solution (group B).

Samples from group A after two weeks of fixation underwent stereomicroscopic dissection. After the dissection, the schematic right coronary artery branching map of each specimen was drawn, and the corresponding morphometric data we entered into the tables.

Samples from group B were obtained after three days of liquefaction in NaOH solution. The hearts were washed in warm water in order to obtain ideal plastic (acrylate) casts of coronary arterial network, which were then used for measurements.

For statistical analysis we used the standard methods of descriptive statistics, the measures of central tendencies and variability measures.

The human anatomy terminology is used in this study (Terminologia Anatomica), with some explanations related to the differences in Nomina Anatomica Veterinaria.

## RESULTS

The right coronary artery (RCA) of CAs originated from the posterior or middle part of the right aortic sinus (*sinus aortae Valsalvae dexter*). In 48 out of 55 hearts (82.3%) its orifice was situated 0.2-1.2 mm above the free edge of the right aortic valve leaflet, and in 7 out of 55 hearts (17.7%) it was 0.3-0.7 mm below it. The longitudinal axis of the aortic root and the initial part of RCA form an angle of $70^{o}$-$150^{o}$ (average of $103^{o}$). The RCA trunk was directed to the right, toward the right part of the coronary groove (*sulcus coronarius*). The external diameter of RCA at its origin ranged from 0.7-1.2 mm (an overage 0.94+/-0.15 mm). In the first millimeters it is submerged in the adipose tissue of the epicardium below the right atrial appendix (*auricula dextra*).

Running in the right part of the coronary groove (or slightly above it), over the sternocostal surface of the heart, RCA took an upward direction in 38 out of 55 hearts (69.1%), horizontal in 9 out of 55 (16.4%) and the downward one in 8 out of 55 hearts (14.5%). In all our cases the epicardial segment of RCA traversed the right margin of the heart (*margo acutus cordis*).

In 41 out of 55 (74.5%) hearts, the first and very constant branch of RCA was the one directed to the arterial cones. Very often it gives rise to numerous small vessels, sometimes forming a delicate epicardial network together with the

corresponding LCA or LAD branches. Obvious similarity in origin and distribution to humans led us to name it conal artery (*ramus coni arteriosi*).

In 47 out 55 (85.5%) cases the sinus node (sinuatrial) artery aroused from the RCA, precisely from its proximal segment. The sinus node artery originated from the RCA reaches the SA node passing behind or in the front atriocaval junction, via the anterior atrial group.

The atrioventricular (AV) nodal artery originating from the RCA was described in 38 out of 55 cases (69.2 %).

The length of the RCA was highly variable. As reference point for its termination we used the anatomical borders of the heart and the *crux cordis*. Rarely its epicardial path terminated at this point as well, and the artery submerged in the myocardium (Figure 1). In 39 out of 55 hearts (70.9%) the RCA goes beyond the *crus cordis*, supplying the posterior interventricular artery – PIVA. We marked it as a long type of RCA, which comprises two possible termination points of RCA. In 35 hearts (63.7%) PIVA was the terminal branch of RCA. In 4 out of 55 hearts (7.2%) after giving off PIVA, RCA proceeded its route to the left margin of the heart, terminating as a posterior left ventricular branch (Figure 2). In 13 out of 55 hearts (23.6%) RCA terminated before reaching the *crus cordis*, as a posterior right ventricular branch (Figure 3). Occasionally, in 3 out of 55 cases (5.5%) RCA terminated as a right marginal branch. The termination point of RCA in 16 out of 55 hearts (29.1%) was at the right half of the diaphragmatic surface. This we defined as a short RCA type.

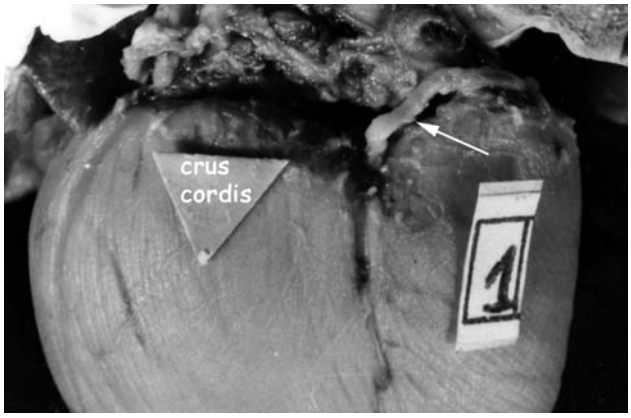


Figure 1. Dorsal aspect of CSa heart. RCA is situated in the coronary groove. Reaching the crus cordis it turns almost rectangularly downwards (80$^{o}$ angle) as PIVA (arrow). It pierces the myocardium after running for few millimeters

Passing along the coronary groove, from the epicardial segment of the RCA successively a number of atrial (ascending) and ventricular (descending) branches arose. These we named rami marginales (Figures 2, 3). Their number varied from 1 to 6, and by their origin and distribution are very similar to the

corresponding ones in humans. They supply the sternocostal side of the right atrium and ventricle, diaphragmatic (dorsal) side of the right atrium and ventricle and 70% of diaphragmatic (dorsal) side of the left atrium and ventricle. The marginal branch descending along the right margin of the heart we have marked as the right marginal artery (*ramus marginalis dexter*).

No significant sexual differences in length and distribution pattern were present.

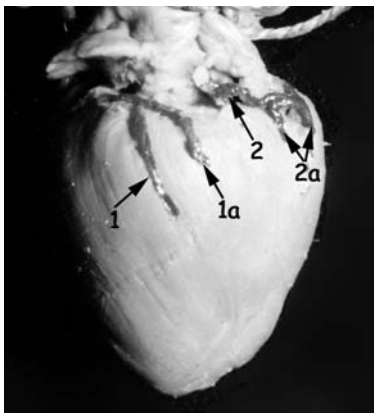


Figure 2. The dominant RCA. Posterior left ventricular arteries (from the RCx, 1, 1a). RCA coursed along the right part of the coronary groove, passed beyond the *crus cordis*, (2); posterior right ventricular arteries of the RCA (2a)

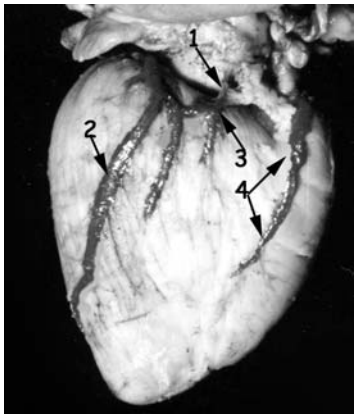


Figure 3. Short type of RCA and consecutive LCA dominance. The A-V node artery arising from RCx(1); *Crus cordis* (2); Emphasized posterior left ventricular branch (3); The RCA terminated before reaching crus cordis (4)

## DISCUSSION

In the studied series of CAs hearts the position of the orifice and axial topography of the RCA are similar to humans. As Vilallonga (2003) reported, coronary orifices of RCA in humans are located in the center of the aortic sinuses and slightly above the free margin of the cusp, what is equivalent to our finding. The most frequent variations in the origin of RCA regarding the aorta wall are mainly observed on cross-sections; the RCA branched off the aorta wall in angles varying from 70$^{o}$-50$^{o}$ (average 103$^{o}$), what resembles the human model as Pejković and Bogdanović (1995) described.

Length and distribution of RCA in our study was highly variable. Most frequently (70.9%) a long type of RCA was found (it coursed beyond the *crus cordis*) and in 29.1% the RCA terminated as a short type at the right ventricle. Among these two types we noticed one extreme variation in length: extremely short type (RCA terminated as the right marginal branch, in 5.5%). The extremely long type (RCA terminating as the left marginal branch) was not found. According to Nomina Anatomica Veterinaria the terminal branch of RCA is a subsinuosal interventricular artery (*ramus interventricularis subsinuosus*). The subsinuosal interventricular artery (SIA) is directed downward, lying in the subsinuosal interventricular groove, anastomosing with the paraconal interventricular branch of the left coronary artery (PIBL). By its direction, branching patterns and irrigation zone, SIA is remarkably similar to PIVA in humans. At the dorsal side of monkey's heart we identified all anatomical structures visible on the diaphragmatic surface in humans as: posterior interventricular groove, *crus cordis*, posterior interventricular artery, AV node and artery. Therefore, we considered it to be diaphragmatic.

The percentage of reported cases in which RCA reaches the crus cordis or passes beyond it, giving off the PIVA in humans varies between 70% and 90% (Baptista *et al*., 1989; Cavalcanti *et al*., 1995, Pejković and Bogdanović, 1995), but there is no doubt that the most frequent finding is the long type of RCA.

Comparative anatomical studies of the right coronary artery distribution in other animals that were considered to be useful experimental models in cardiovascular research did not show the necessary similarity with human hearts. Namely, studies of the rabbit revealed that the RCA has never found to be the dominant vessel (Podesser *et al*., 1997). The same percentage of the RCA dominance was reported in goats (Yang *et al*., 1989). The PIVA arose from the RCA in 56% of the hearts of bonnet monkeys – *Macaca radiata* (Buss *et al*, 1982), in 78% pigs (Weaver *et al*., 1986) in 45% *Macaca fascicularis* (Teofilovski *et al.*, 1993).

The origin and route of RCA branches are very much alike that in humans. In our study, the first branch of RCA in CAs most frequently was the conal artery. This being similar to the some previously published studies of human hearts (Hadžiselimović, 1982; Allwork, 1987; Pejković and Bogdanović, 1995), where incidence varied between 48%-60%. Studing monkey hearts Nikolić *et al*. (2004) reported a conal artery that originated from the right aortic sinus, which is a common finding in humans (Pejković and Bogdanović, 1995).

The sinus node (SA nodal) artery more frequently arises from RCA in CAs hearts (Blagojević, 1989). It is well known that RCA is more frequently the source of blood supply of the human SA node. Published results vary in percentages, between 54%-70% (Roberts, 1961; Kamenica *et al*., 1985; Villalonga, 2003).

Among animals, SA nodal artery arose from RCA in 7.9% baboons (Papio Erxleben, 1977; de Lacerda et Huerau, 1986), in 100% pigs (Weaver *et al*., 1986), in 62% goats (Yang *et al*., 1989), in 55% *Macaca fascicularis* (Teofilovski *et al*., 1993), in 30% dogs (Ovčina, 2002).

Habitually, the AV node is irrigated by the artery that reaches the *crus cordis* and supplies the PIVA, although coronary dominance does not automatically reflect the origin of the AV node artery. The AV node artery arose from RCA in 69.2%, which is quite fitting to the incidence of long type of RCA. The vascularization of the AV node in humans is more or less close to these results. Villalonga (2003) reported that AV nodal artery originated from RCA in 86% of cases, but other authors reported an incidence of 90-92% (Roberts, 1961; Kamenica *et al*., 1985).

In the 69% bonnet monkeys (*Macaca radiata*) the AV node was supplied by a branch of the RCA in 69% (Buss *et al*., 1982), in baboons with same frequency as in humans i.e. 82% (de Lacerda et Huerau, 1986) and in goats AV node artery originates from LCA exclusively (Yang *et al.*, 1989).

Our investigation has revealed that the branching fashion of the RCA resembles the one in humans. From the trunk of the RCA arose numerous branches forming the subepicardial vascular network as seen in the human.

Considering the previous data we could realize that the irrigation of the sternocostal surface of the CAs heart is extremely regular. The dorsal surface is supplied by two arteries, that gives-out each heart its own physiognomy. Therefore, we may determine that RCA typically supplies the right atrium, right ventricle, interventricular septum (posterior part), SA and AV nodes, and AV bundles. It also supplies a variable part of the left atrium and left ventricle.

In conclusion, RCA anatomy of the CAs resembles to the human analogue more closely than other compared animals in terms of distribution, origin of PIVA, supply of SA and AV nodes and branching pattern. Therefore, the CAs may be a useful model for functional studies on coronary circulation.

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## DISTRIBUCIJA DESNE KORONARNE ARTERIJE U ZELENOG AFRIČKOG MAJMUNA

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SADRŽAJ

Proučavanje distribucije desne koronarne arterije (DKA) i njenih grana na srcu zelenog afričkog majmuna (CAs) sprovedeno je sa ciljem da se dobiju osnovne informacije o mogućnosti primene CAs u kardiovaskularnim istraživanjima. Naša studija je obavljena na 55 srca majmuna dobijenih nakon žrtvovanja životinja korišćenih za izradu vakcina na Institutu za imunologiju i virusologiju Torlak, na način predviđen strogim etičkim normama. Radi bolje vizuelizacije, koronarne arterije su in situ injektirane Latex-om ili tuš-želatinom (serija A), odnosno Symgalom (serija B). Naši rezultati ukazuju da se ušće DKA kod CAs, kao i kod čoveka, nalazi u središnjem delu desnog aortnog sinusa, neznatno iznad slobodne ivice zaliska (82.3%). DKA je čećše dosezala *crus cordis* (70.9%) i dajući *r. interventricularis posterior* vaskularizovala zadnji deo srčane pregrade, što je u skladu incidencom dominantnosti DKA u čoveka. Ekstremno dugi tip je prisutan u 7.2 %, a ekstremno kratki u 5.5% slučajeva. Prva grana DKA je vrlo često (74.5%) bila *a. coni arteriosi*, što je slučaj i kod čoveka. Arterija za vaskularizaciju SA nodusa je najčešće (85.5%) bila grana DKA. Slično tome, i grana za vaskularizaciju AV čvora se češće (69.2%) odvajala od DKA. Broj nishodnih grana (*rami marginales*) DKA varirao je između 1 i 6, a njihova distribucija ukazuje na evidentnu sličnost sa koronarnom šemom DKA u čoveka. Naši rezultati nisu pokazali statistički značajnu razliku u dužini DKA, broju i distribuciji njenih grana u odnosu na pol životinje. Rezultati našeg istraživanja ukazuju na postojanje izvanredne sličnosti u distribuciji DKA i njenih grana kod CAs i čoveka, što uz podudarnost irigacionih zona, čini da CAs preporučimo kao dobar eksperimentalni model u kardiovaskularnim istraživanjima.