Research Paper: Morphology of the Great Cardiac Vessels in Egyptian Fruit Bat (*Rousettus aegyptiacus*)

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Citation Kamali Y, Ghasemi F. Morphology of the Great Cardiac Vessels in Egyptian Fruit Bat *(Rousettus aegyptiacus)*. Anatomical Sciences. 2021; 18(2):79-84.

Article info:
Received: 03 Mar 2021
Accepted: 23 May 2021
Available Online: 01 Jul 2021

Keywords:
Anatomy, Egyptian fruit bat, Large vessels, Heart

ABSTRACT

Introduction: The purpose of this study was to describe the anatomic appearance of great cardiac vessels in the Egyptian fruit bat (*Rousettus aegyptiacus*) as a common bat living in the southern region of Iran.

Methods: Five Egyptian fruit bats with a Mean±SD body mass index (BMI) of 123.04±0.08 g were selected and studied.

Results: The aortic arch (transverse arch) cranial to the heart gives rise to the right and left brachiocephalic (innominate) arteries, each of which immediately divides into common carotid and subclavian arteries. The aortic arch continues caudally on the dorsal side of the heart, inclines to the left of the median plane as the dorsal aorta. The ligamentum arteriosum connecting the dorsal aorta to the pulmonary trunk is seen a few millimeters caudal to the origin of the left brachiocephalic artery. The arrangement of the great veins, including two anterior venae cavae, resembles that found in birds rather than mammals. A left azygos vein entered dorsally to join the left anterior vena cava. The opening of the right anterior vena cava is in the dorsal part of the right atrium; the opening of the left anterior vena cava, similar to the coronary sinus, is at the caudal part of the right atrium. The posterior vena cava opens into the right atrium dorsal and cranial to the entrance of the left anterior vena cava.

Conclusion: The evolution in the morphology mentioned above is in accordance with the flight requirements of bats.

1. Introduction

In mammals, several great vessels are directly connected to the heart, including the ascending aorta, pulmonary trunk, pulmonary veins, the superior vena cava, and the inferior vena cava. The ascending aorta arises from the left ventricle and curves back over the heart to form the aortic arch. It becomes the descending thoracic aorta as it continues downwards through the thorax. The number of branches that arise directly from the aortic arch differs from one to four, depending on mammal species [1]. Two large veins, namely the cranial vena cava and caudal vena cava, drain deoxygenated blood into the right atrium of the heart from the upper and lower body, respectively. The cranial vena cava is formed by merging two brachiocephalic (innominate) veins at the thoracic inlet

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[2]. The latter receives blood on each side from the external jugular and subclavian veins [2].

Bats are unique among mammals in their ability to fly. To adapt to this ability, anatomical variations of their organs, such as the heart and large vessels, are not unexpected [3-5]. Egyptian fruit bat (*Rousettus aegyptiacus*) belongs to the suborder megachiroptera found in diverse habitats in the southern region of Iran [6]. A review of the literature disclosed little knowledge about the arrangement of the great vessels in the bats. One report conducted by Parsons presented a description of the arrangements of the aortic arch branches in several mammals, including the Chiroptera, Edentata, and Cetacea orders [7]. Detailed anatomic descriptions of the heart and position of its great vessels are given in several species belonging to microchiropterans, macrochiropterans, and some new world bats [8-10]. These studies have focused on the structure of bats' hearts in detail and less on the morphology of the vessels around the heart. Data on the morphology of the great vessels at the base of the bat's heart has generally been presented as schematic drawings. However, minor variations in the architecture of the heart great vessels may be seen in different species of bats. These anatomical variations in the great vessels of the heart may have evolved according to its habitat conditions.

Nonetheless, no detailed examination has been made in the great vessels of the heart in Egyptian fruit bats. Knowledge of the anatomy of great cardiac vessels could provide new insights into the evolution of bats and may be helpful to biological and biomedical researchers investigating the anatomy and physiology of the heart. Thus, this study aimed to provide further details on the morphology and anatomic appearance of great cardiac vessels in Egyptian fruit bats.

2. Materials and Methods

In the present study, 5 Egyptian fruit bats (*Rousettus aegyptiacus*) were captured by mist net in the Zorok Cave (Fars Province, Iran). They were transferred to the Veterinary Dissecting Unit of Shiraz University in a cloth bag, anesthetized with ether, and weighed immediately after death. Their Mean±SD body mass was 123.04±0.08 g. The specimens were embalmed with standard formaldehyde solution. Using a stereomicroscope (ZSM-1001), the thoracic cavity was opened, and after removal of the lungs, the pericardium covering the heart, aorta, and great vessels was carefully dissected and photographed. All the experimental procedures were done in compliance with the National Institute of Health for using laboratory animals.

3. Results

The ascending aorta cranial to the base of the heart turns to the left and crosses the median plane to form the aortic arch (transverse arch). It gives rise to the right and left brachiocephalic (innominate) arteries, each of which immediately divides into common carotid and subclavian arteries (Figure 1). The aortic arch continues caudally on the dorsal side of the heart, inclines to the left of the median plane as the dorsal aorta. The pulmonary trunk arises from the summit of the conus arteriosus of the right ventricle. After passing underneath the transverse aorta, it bifurcates into two un-

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Figure 1. The great vessels cranial to the heart in ventral view

Ascending Aorta (AA), Transverse Aorta (TA), Dorsal Aorta (DA), Left (Lia) and Right (Ria) innominate arteries, Subclavian artery (Sa), Common Carotid artery (CCa), Left (Lavc) and Right (Ravc) anterior venae cavae, Right Auricle (RA)

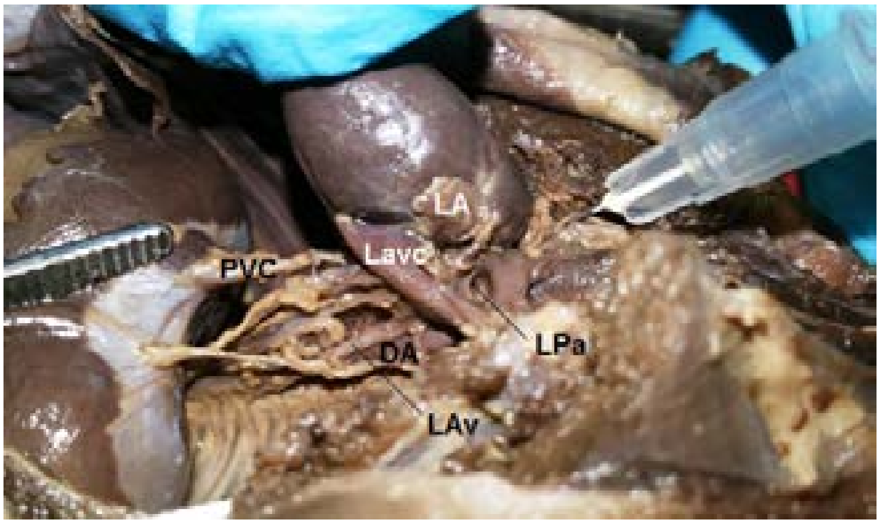

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Figure 2. Left Azygos vein (LAv) draining into the Left anterior vena cava (Lavc); Posterior Vena Cava (PVC), Dorsal Aorta (DA), Left Pulmonary artery (LPa), Left Auricle (LA) in left ventrolateral view of the thorax

equal pulmonary arteries cranial to the left atrium (Figure 2). The ligamentum arteriosum connecting the dorsal aorta to the pulmonary trunk is seen a few millimeters caudal to the origin of the left brachiocephalic artery. The arrangement of the great veins, including two anterior venae cavae formed by the confluence of subclavian and jugular veins, resembles the arrangement found in birds rather than mammals. A left azygos vein entered dorsally to join the left anterior vena cava (Figure 3). Externally, the left anterior vena cava passes caudally then turns medially caudal to the pulmonary veins. Along with the right anterior vena cava, it forms a loop around the dorsal aspect of the right atrium (Fifure 4). The posterior vena cava joins the loop dorsally just to the right of the median plane. The opening of the right anterior vena cava is in the dorsal part of the right atrium, whereas the left anterior vena cava with the coronary sinus enters the caudal part of the right atrium. The posterior vena cava opens into the right atrium dorsal and cranial to

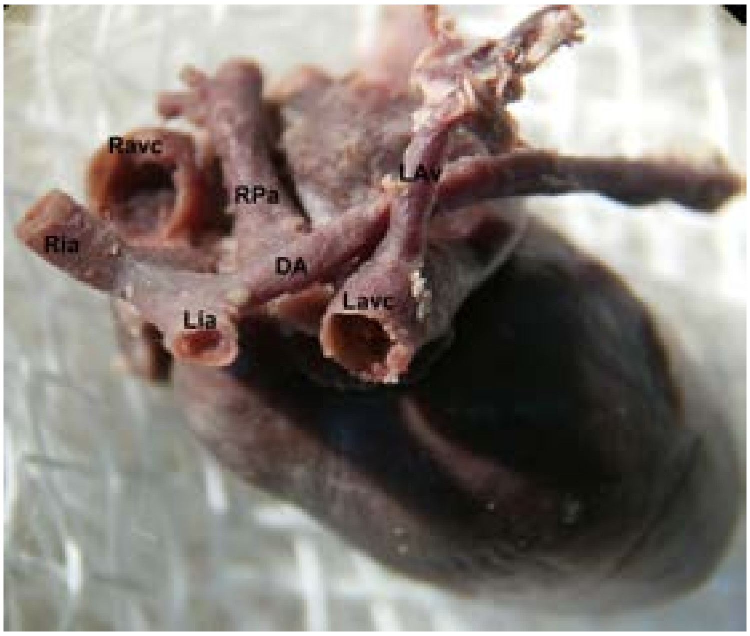

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Figure 3. Right Pulmonary artery (RPa), Left (Lavc) and Right (Ravc) anterior venae cavae, Left Azygos vein (LAv) in dorsal aspect of the heart
Note the equal size of the Left (Lia) and Right (Ria) innominate arteries with the Dorsal aAorta (DA).

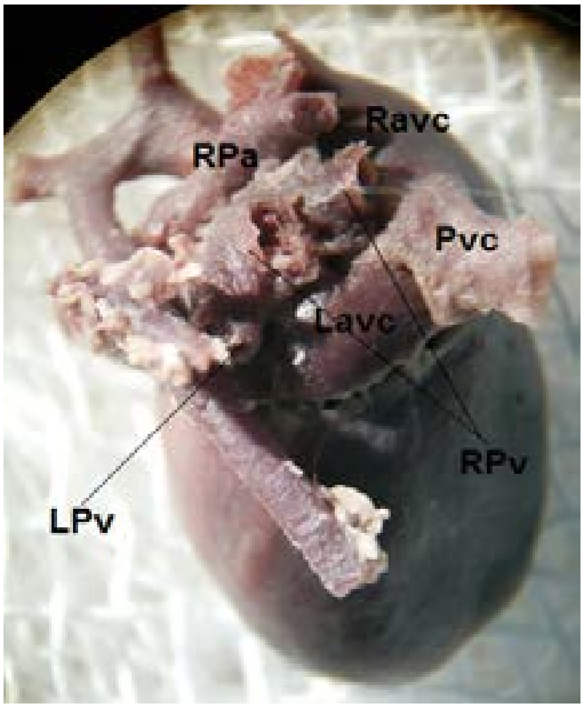

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Figure 4. Posterior aspect of the base of the heart
Left (Lavc) and Right (Ravc) anterior venae cavae, Posterior Vena Cava (PVC), Right (RPv) and Left (LPv) Pulmonary veins, Right Pulmonary artery (RPa).

the entrance of the left anterior vena cava. There are three pulmonary veins: one left pulmonary vein and two larger right pulmonary veins that each drains separately into the dorsal wall of the left atrium (Fifure 4).

4. Discussion

This study describes the gross anatomy of the great vessels of Egyptian fruit bat. The branching patterns of the aortic arch vary among different mammals [1, 7]. In the most specialized aortic arrangement that has been described in humans [11], monkeys [12], and some other mammals [13-15], the aortic arch gives off three collateral arteries. On the right side, the fusion of the right common carotid and subclavian arteries forms the innominate artery, whereas the left counterparts of these arteries remain separate. In mammals with two collateral branches of the aortic arch, fusion becomes more extended, involving the left common carotid artery as well, and the left subclavian artery arises separately from the aortic arch. This arrangement is observed in pigs, dogs, and cats [2], as well as other exotic animals such as the white-eared opossum [16] and Chinchilla lanigera [3, 17]. It has been reported that two branches of the right brachiocephalic trunk and left brachiocephalic trunk, leave the aortic arch in the Chiroptera, Edentata, and Cetacea order bats [7, 8]. Each brachiocephalic trunk (innominate artery) is formed by the union of the common carotid and subclavian arteries. Similarly, in birds, right and left brachiocephalic trunks also originate from the aortic arch [18, 19]. The symmetrical bi-innominate arteries of equal size arising from the aortic arch of five dissections of Egyptian fruit bat in the present study agree with the branching pattern of the order Chiroptera [8]. This arrangement of the aortic arch branching is much more similar to that of birds than to mammals. The diameter of each brachiocephalic artery is usually the same as the continuation of the aorta, reflecting the higher blood flow rates toward the head, wings, and flight muscles.

Previous studies in the heart of the megachiropterans and micropchiropterans have shown that structural differences were negligible except for a few minor variations in venous drainage [8, 10, 20]. The presence of a single left pulmonary vein and two groups of right pulmonary veins draining into the left atrium of the megachiropterans R. aegyptiacus was in complete agreement with the account given by Grosser and Rowlatt [8, 10].

Another unusual feature was the symmetry in the arrangement of the great veins cranial to the heart that indicates a return toward a more primitive condition in which both anterior (cranial) venae cavae are retained to perform a specific function as part of the overall upper limb requirement for flight. In mammals, during embryonic development of the venous system with a caudal displacement of the heart, a transverse anastomosis is formed between the two cranial cardinal veins to shift the blood flow to the right side. Thus, the proximal portion of the left cranial cardinal vein undergoes degeneration [21]. In carnivores, the left brachiocephalic vein arises from the mentioned anastomosis and the right brachiocephalic vein from the proximal portion of the right cranial cardinal vein. Two large veins, i.e., the right and left brachiocephalic join to form the cranial vena cava. In ungulates, the jugular and subclavian veins drain directly into the cranial vena cava [21]. It seems that during the development of large veins in bats, the anastomosis mentioned above is not formed between the two cranial veins. Park described the two anterior veins draining into the right atrium as the innominate veins in four new world bats [9]. Other researchers have described two anterior venae cavae of the same size by the coming together of the subclavian, vertebral, and jugular veins in several species belonging to the megachiropterans and microchiropterans [8, 10, 20]. The greater size of the anterior venae cavae than the posterior vena cava is attributed to the larger size of the upper limbs.

In all five specimens dissected, the azygos vein drains into the left anterior vena cava. This vessel has been shown to exist on the right side or bilaterally [10].

5. Conclusion

Understanding the significance of these morphogenetic changes is difficult, and the information presented here is mainly objective. Most of these changes are not necessarily related to adaptive changes because a large set of bat species that are phylogenetically close together but live in different ecologies show almost the same morphology pattern in the great vessels around the heart.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the Shiraz University.

Funding

This study was funded by School of Veterinary Medicine, Shiraz University.

Authors' contributions

Investigation, writing original draft: Younes Kamali; Review & editing: Farangis Ghassemi.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors would like to thank the Department of the Environment (Shiraz Office) for supporting this research.

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