Pakistan J. Zool., vol. 48(6), pp. 1681-1686, 2016.

A Study on Branching of Aortic Arch in the Greater Flamingo (*Phoenicopterus roseus*, Pallas 1811)

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ABSTRACT

This study was aimed to investigate of the anatomy of the aortic arch and the distribution of its main branches in the greater flamingo. For this purpose, five flamingos, two of which were female and three were male, were used. The vascular anatomy was demonstrated by latex injection method. It was observed that two brachiocephalic trunks branched off from the ascending aorta in the greater flamingos. The subclavian and common carotid arteries stemmed from these two trunks. Along its cranial course, the subclavian artery first gave off the sternoclavicular artery, and then the axillary artery, intercostal artery and finally internal and external thoracic arteries. The common carotid arteries were observed to give off the tracheosyringeal branch, which supplied the syrinx and trachea, and the thyroid artery, which supplied the thyroid gland. The left common carotid artery terminated after sending off branches to the syrinx and the neck. While the right common carotid artery gave off branches similar to those of the left common carotid artery, after giving off these branches, it coursed to the head as a single artery in the ventral part of the neck. In all of the flamingos, the presence of the right unilateral common carotid artery was noteworthy. It is considered that the species-specific information obtained in this study, for the aortic arch and its branches in the flamingo, would contribute to the understanding of the circulatory system in these water bird species, as well as to future comparative studies.

Article Information
Received 10 November 2015
Revised 4 March 2016
Accepted 15 April 2016
Available online 25 September 2016

Authors' Contribution
AD designed the study. AD and AA obtained materials. AA and IO performed dissections and analyzed the data. AA wrote the article.

Key words
Anatomy,
Aortic arch,
Flamingo,
Unicarotid

INTRODUCTION

In avian species, the ramification of the cardiac arteries differs from that in mammalian species. The ramification of the cardiac arteries is mainly determined by the aorta and the two brachiocephalic trunks. These trunks extend to the right and left, and along their course firstly give off the common carotid and subclavian arteries (King and McLelland, 1984). Nevertheless, this ramification pattern differs among bird species (Nickel *et al.*, 1977; King and McLelland, 1984; Baumel *et al.*, 1993).

The common carotid arteries and the subclavian artery supply the head, the cervical and pectoral regions, and the wings. The thoracic artery, which is the largest branch of the subclavian artery, is the main blood vessel that supplies the pectoral region (Nickel *et al.*, 1977). The sternoclavicular artery, axillary artery, intercostal arteries and thoracic artery, stem from the subclavian artery in this region (Erdogan and Kiline, 2014). In some flightless birds such as kiwi, the thoracic arteries supplying the pectoral muscles are smaller and have been modified into the pectoral-axillary arteries (Glenny, 1942b).

When we compared the researches in mammalian species, studies conducted on the circulatory system of avian species are fewer and inadequate. Especially there are few studies related to wild bird species. Although information on the circulatory system and the ramification of the aortic arch in avian species is available in several books and atlases, the most detailed information acquired to date, is provided in the reports of the systematic studies carried out by Glenny in several bird species (Glenny, 1944, 1945a, 1948a, 1953a). Despite the significant contribution made by recent studies carried out in several avian species, including the duck (Kürtül and Hazıroğlu, 2004), buzzard (Haligür and Düzler, 2010), chicken (Kuru, 2010), quail (Düzler *et al.*, 2011), budgerigar (Radek and Piasecki, 2004) and eagle owl (Aycan and Duzler, 2000) etc., there is still need for further studies to fill the literature gap.

This study was aimed to fulfil the need for anatomical information and to contribute future studies and the better understanding of this species.

MATERIALS AND METHODS

Two female and three male greater flamingos (*Phoenicopterus roseus*) were used in this study. Of these birds, two had died during treatment, after being admitted to the surgery clinic of Erciyes University, Faculty of Veterinary Medicine, due to traumatic wounds. The other three greater flamingos had been brought dead to the Faculty of Veterinary Medicine by a bird watcher. The mean body weight of the birds was measured as 2.83 kg (from 2.7 to 3.15 kg). Their wingspan ranged between

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0030-9923/2016/0006-1681 $ 8.00/0

130 and 186 cm, and their height ranged from 120 to 159 cm. The latex injection method was used to observe arteries. Through the left ventricle, latex coloured with red ink was injected into the ascending aorta. After being kept in a refrigerator for a period of 48 hours for fixation of the latex. Subsequently, the flamingos were dissected under an Olympus ZS STB1 microscope (Olympus corporation, Japan).

RESULTS

In the flamingos, the heart was situated in between the 1st and 3rd intercostal spaces. It was observed that two brachiocephalic trunks originated from the ascending aorta at the level of the cardiac base (Fig. 1).

The mean diameter of the aorta was determined as 9.8mm at its origin and as 6.9mm after giving off the brachiocephalic trunks. The mean diameters of the left brachiocephalic trunk, which arose in the first place from the ascending aorta, and the right brachiocephalic trunk, which stemmed from the ascending aorta immediately after the origin of the left trunk, were determined to be 6.5mm and 7.3mm, respectively. A mean angle of 65 degrees was measured between the two brachiocephalic trunks.

The common carotid and subclavian arteries originated from the brachiocephalic trunks at a mean distance of 21 mm to the origin of the right trunk, and 15 mm to the origin of the left trunk (Fig. 1). It was determined that the diameter of the right carotid artery (3.2 mm) was approximately two-fold of the diameter of the left carotid artery (1.7mm).

Firstly, the tracheosyringeal trunk branched off from the common carotid arteries (Fig. 2). In the proximity of the trachea, the tracheosyringeal trunk bifurcated into the tracheal artery, which extended cranially, and the syringeal artery, which extended caudally, to supply the relevant organs.

After the ramification of the tracheosyringeal trunk, the ascending oesophageal arteries arose from the common carotid arteries, from the ventral surface on the right and the dorso-lateral surface on the left. Shortly after their origin, these arteries gave off the cranial and caudal thyroid arteries (a. thyroidea cranialis et caudalis) (Fig. 2). Moreover, it was observed that two thyroid arteries coursed to the thyroid gland. The thyroid glands were adherent to the ventral surface of the ascending oesophageal artery on both sides (Fig. 2-G).

Along their continued course in cranial direction, on both sides, the carotid arteries symmetrically gave off the transverse cervical artery (a. transversa colli), superficial cervical artery (a. comes nervi vagi), ascending cervical cutaneous artery and vertebral trunk, which extended dorsolaterally. After giving rise to these branches, it was observed that the left common carotid artery terminated in the surrounding tissues at the level of the16thcervical vertebra and did not course to the head.

On the right side, after displaying the mentioned branching, the right common carotid artery was observed to pass medially and settle into the cervical carotid canal, otherwise known as the osteomuscular canal, and to course to the head. This finding demonstrated the presence of the right unicarotid form in the flamingo (Fig. 2).

The subclavian artery, the other branch of the brachiocephalic trunk, was larger on the right side (7.6-6.4 mm) (Fig. 1). The subclavian arteries extended sideways, and gave rise to the sternoclavicular artery, thoracic artery, axillary artery, intercostal artery, and the major coracoid artery. The origin of the sternoclavicular artery was situated ventral to the origin of the axillary artery. The sternoclavicular artery divided into two branches, namely, the sternal artery and the clavicular artery, both of which supplied the pectoral muscles and the proximal part of the thorax. The axillary artery, shortly after its origin, gave rise to a fine branch, namely, the minor coracoid artery and continued with its course to the wing (Fig. 1).

The largest branch of the subclavian artery, which appeared to be its continuation, was the thoracic artery and had a short and thick body. Along its caudal course, the coracoid major artery and the intercostal artery branched off from the thoracic artery. Thereafter, the thoracic artery divided into the internal and external thoracic arteries, both of which supplied the deep pectoral muscles and the thoracic wall (Fig. 1).

DISCUSSION

Contrary to literature reports, which suggest the brachiocephalic trunks to have their origin at the aortic arch (Nickel *et al.*, 1977; King and Mc Lelland, 1984; Baumel *et al.*, 1993), it was determined that in the flamingos examined in the present study, the brachiocephalic trunks arose from the ascending aorta. In agreement with literature data (Erdogan, 2012), the brachiocephalic trunks were observed to have divided into the common carotid artery and the subclavian artery. Erdogan (2014) reported that, in the buzzard, the left trunk branched off before the right trunk. The same ordinal branching pattern was observed in the flamingos examined in the present study. Furthermore, it was observed that the right trunk was larger than the left trunk.

The common carotid and subclavian arteries supply the head as well as the cervical and pectoral regions (Nickel *et al.*, 1977). Similar to the findings obtained in

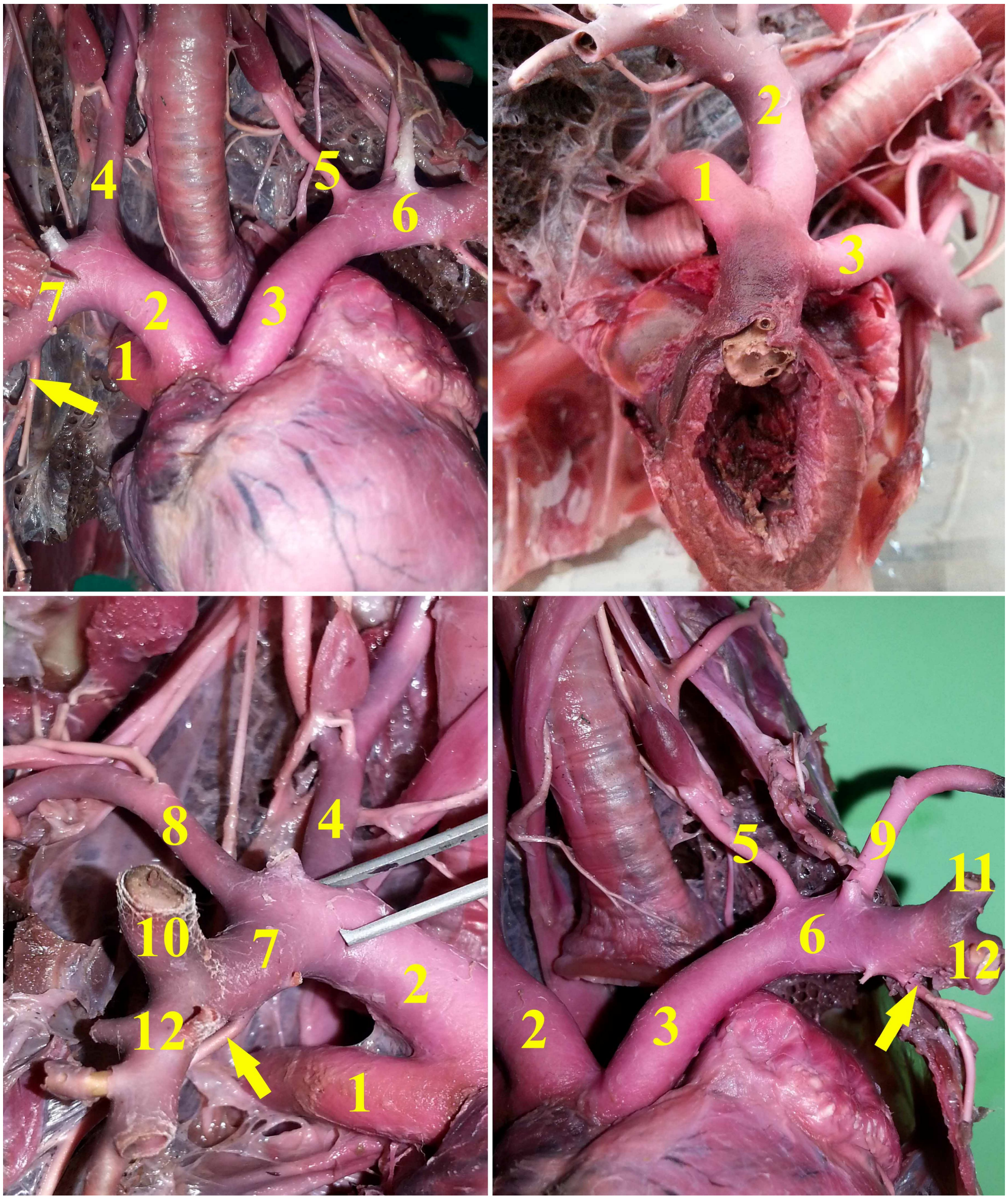

Fig. 1. Branching of aortic arch in the greater flamingo, *Phoenicopterus roseus;* 1, aorta, right (2) and left (3) brachiocephalic trunk; right (4) and left (5) common carotid artery; left (6) and right (7) subclavian artery; right (8) and left (9) axillar artery; right (10) and left; 11, internal thoracic artery; 12, external thoracic artery (right and left) Arrow: Coracoid major artery.

the present study, literature reports (Glenny, 1945a, 1948a; Erdogan, 2012) also indicate that the common carotid artery gives rise to the internal carotid artery, thyroid artery, vertebral trunk, tracheosyringeal artery and superficial cervical artery. Furthermore, it has also been reported that the common carotid artery gives rise to

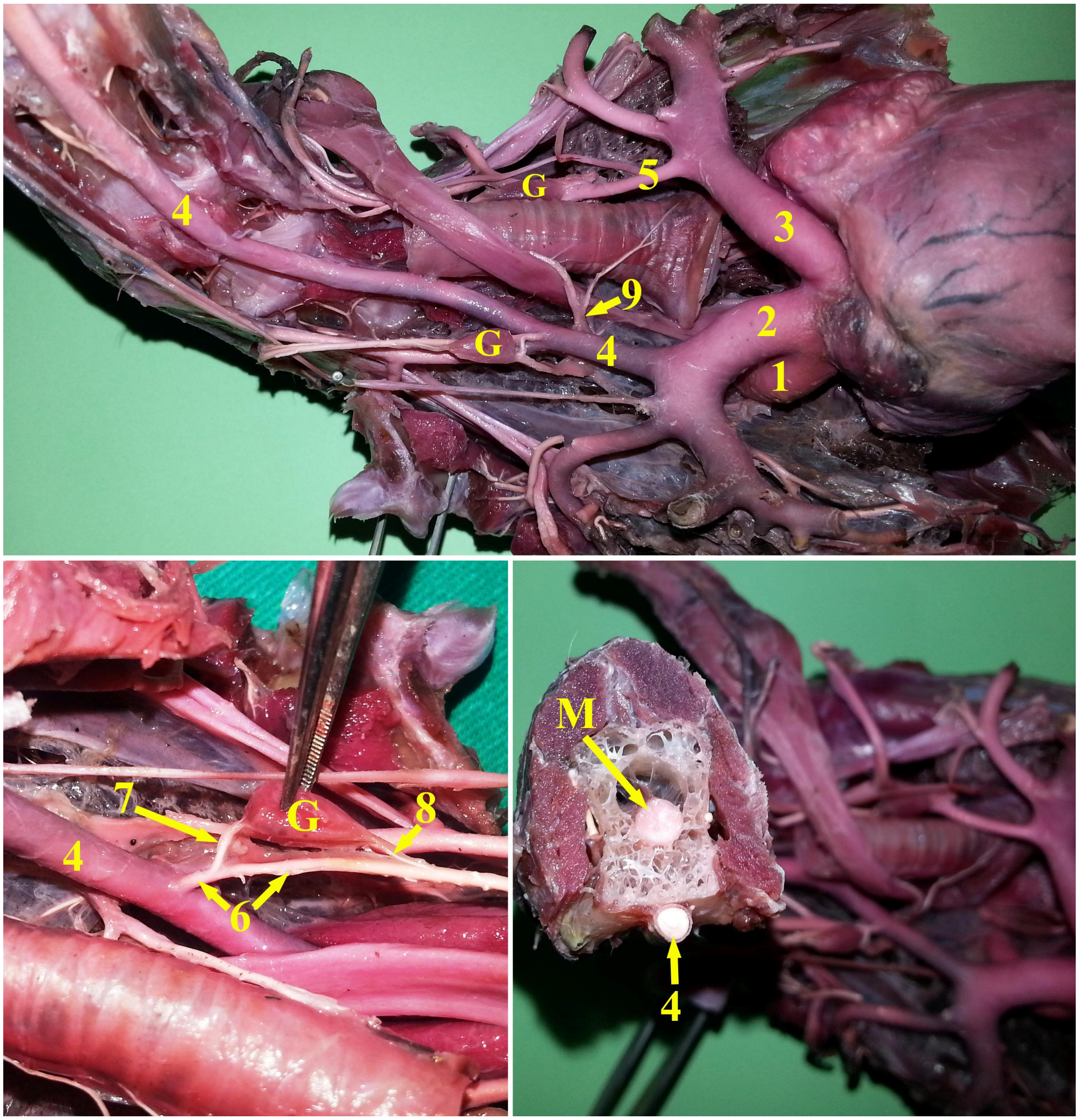

Fig. 2. Branching of aortic arch in the greater flamingo, *Phoenicopterus roseus;* 1 aorta; right (2) and left (3) brachiocephalic trunk; right (4) and left (5) common carotid artery; 6, ascending esophageal artery; caudal (7) and cranial (8) a, thyroidae; 9, ramus tracheosyringealis; G, Gl. mhyroidea; M, medulla spinalis.

the oesophageal branch in the Eurasian bittern (Erdogan, 2012) and to the mesoesophageal artery at the level of the furcula, as indicated by Glenny (1944, 1945a, 1948a, 1953a). In the present study, while the ascending oesophageal artery originated from the common carotid artery, on the contrary to the report of Glenny (1945a), the accessory oesophageal artery did not exist.

Reports indicate that the origin of the thyroid artery varies among avian species. In the budgerigar (Radek and Paresecki, 2004), three thyroid arteries, which originate from the oesophagotracheobronchial and ascending oesophageal arteries and are referred to as the cranial, middle and caudal arteries, exist. The number of thyroid arteries has been reported to increase up to 6 in some individuals of this species. While the thyroid artery has been ascertained to stem directly from the brachiocephalic trunk in the kiwi (Glenny, 1942b), it has been shown to originate from the carotid artery in the

Eurasian bittern (Erdogan, 2012). In the flamingos of the present study, the thyroid gland was supplied by the cranial and caudal thyroid arteries, and similar to the report of Radek and Paresecki (2004), but contrary to the reports of Glenny (1942a) and Erdogan (2012), these arteries originated from the ascending oesophageal artery.

The majority of bird species are bicarotid and the two carotid arteries run adjacently within the osteomuscular canal (cervical carotid canal), along the ventral surface of the cervical vertebrae (Baumel *et al*., 1993). In previous research conducted by Glenny on birds belonging to the family Fringillidae (1942b), order Coliiformes (mousebirds) (1944) and genus Parus (tits) (1945b), it was determined that these species were unicarotid and possessed a permanent left carotid artery. Similarly, all of the flamingos in the present study were observed to be unicarotid. However, on the contrary to the reports of Baumel *et al.* (1993) and Glenny (1942a,b, 1944, 1951, 1953), it was ascertained that the right carotid artery was permanent.

It has been reported that the sternoclavicular artery, axillary artery, intercostal artery and coracoid major artery originate from the subclavian artery and that the ordinal branching pattern of these arteries varies among species (Erdogan, 2012; Glenny, 1944, 1945a, 1953a, b). To exemplify, the order of the arteries branching from the subclavian artery is the axillary, coracoid major, pectoral and intercostal arteries in the *Grus americana* (whooping crane) (Fisher, 1955), the axillary, pectoral, intercostal and coracoid major arteries in the *Grus antigone* (sarus crane) (Glenny, 1947), and the sternoclavicular artery, axillary artery and thoracic trunk in the Eurasian bittern (Erdogan, 2012). In the flamingos, the order of branching was determined as the axillary, sternoclavicular, intercostal and coracoid major arteries and thoracic trunk, respectively. While the branches arising from the subclavian artery along its course were found to be the same with those indicated in literature reports, the ordinal branching pattern was observed to differ from that reported in other species. Raether (1964) attributed differentiation in the vascularisation pattern to the localisation of large blood vessels in the thoracic region and to the topographical relations between the organs.

Glenny (1953b) reported that, while two sternoclavicular arteries stemmed from the subclavian artery in the family Trochilidae (humming birds), no sternoclavicular artery existed in the family Fringillidae (finches) (Glenny, 1942b). Literature reports indicate that the axillary artery originates from the subclavian artery in the orders Passeriformes (perching birds) (Glenny, 1945b), Coliiformes (mouse birds) (Glenny, 1944), Trogoniformes (trogons) (Glenny, 1948b) and Gruiformes (cranes, limpkins, rails, gallinules, coots, bustards) (Glenny, 1947), as well as in the Eurasian bittern (Erdogan, 2012). In the present study, a single sternoclavicular artery and axillary artery were observed to stem from the subclavian artery at the same level.

It has been reported that the coracoid minor artery alone stemmed from the axillary artery in the order Coliiformes (Glenny, 1944) as well as in the *Fulica americana* (American coot) (Glenny, 1947), whereas the coracoid minor artery, together with the coracoid major artery, stemmed from the axillary artery in the *Anthropoides paradisea* (blue crane) (Fisher, 1955). Furthermore, the coracoid major artery has been reported to originate from the subclavian artery in the orders Coliiformes (Glenny, 1944), Columbiformes (pigeons and doves) (Glenny, 1946) and Trogoniformes (Glenny, 1948b), as well as in the family Fringillidae (Glenny, 1942b). The coracoid major and coracoid minor arteries have been determined not to exist in the Eurasian bittern (Erdogan, 2012). In the present study, the coracoid minor artery was ascertained to stem from the axillary artery as a fine branch, whereas the coracoid major artery was ascertained to originate from the thoracic artery.

The intercostal artery has been reported to arise from the subclavian artery in the family Fringillidae (Glenny, 1942b), in the *Ara-ararauna* (blue and gold macaw) (Glenny, 1951), in the American bittern by Glenny (1940) and in the *Grus americana* (whooping crane) by Fisher (1955). Erdogan (2012) suggested that the intercostal artery is the branch of the brachiocephalic trunk in the Eurasian bittern. Similar to literature reports, the intercostal artery arose from the subclavian artery in the flamingos of the present study. Furthermore, in agreement with previous reports on avian species (Nickel *et al.*, 1977; Erdoğan, 2012), it was determined that the acromial artery did not originate from the subclavian artery in the flamingos.

In flightless birds (Glenny, 1942a), the thoracic arteries supplying the pectoral muscles have a finer structure. However, as flamingos are migratory birds, contrary to the case in the kiwi (Glenny, 1942b), the thoracic arteries were observed to be large blood vessels that were in fact the continuation of the subclavian artery.

On the basis of the brachiocephalic trunks originating from the ascending aorta and these trunks having a diameter almost equal to that of the aorta in the flamingo, it is considered that two-thirds of the blood pumped by the heart is supplied to the pectoral muscles, head and wings by the ascending aorta, while one-third of the blood pumped by the heart is supplied to the body by the descending aorta. This phenomenon may demonstrate the high vascularisation capacity of the pectoral and brachial muscles of the flamingo, which is a migratory bird that can fly over long distances. Furthermore, the right brachiocephalic trunk being larger than the left brachiocephalic trunk was also in support of the conclusion that the flamingo is a unicarotid species with a permanent right carotid artery.

The authors consider that the findings obtained in the present study would contribute to the better understanding of the morphological and phylogenetic relations between different species. The specific anatomical data obtained in this study is hoped to constitute reference information for future research to be conducted in this area.

Conflıct of interest statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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