Original Article

COLLATERAL BRANCHES OF THE AORTIC ARCH IN THE GREATER RHEA (*Rhea americana americana* LINNAEUS, 1758)

RAMOS COLATERAIS DO ARCO AÓRTICO DE EMAS (Rhea americana americana LINNAEUS, 1758*)*

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ABSTRACT: The greater rhea (*Rhea americana americana*) is a bird of the Rheidae family, and is known as a ratite for being a flightless bird. This animal has great reproductive and productive potential, according to the products and by-products that it can provide such as meat, leather, feathers and fat which are very popular in the world market. Given its economic importance and lack of information in the literature on its morphology, especially in regard to its cardiovascular apparatus, this study aimed to describe the collateral arteries of the aortic arch, in order to establish the origin and distribution of arteries and thus contribute information to the biology of the species. The bodies of 20 young and adult rheas of both sexes which had died from natural causes and were being stored in a freezer at CEMAS / UFERSA were used. The study was approved by CEUA /UFERSA (Opinion No. 09/2015, process No. 23091.004968 / 2015-23). The animals were thawed and had the cannulated thoracic aorta artery and the vascular system perfused with Neoprene 450 latex colored with yellow pigment. Subsequently, the animals were fixed in 3.7% aqueous solution of formaldehyde, and after 72 hours dissections were carried out, images were obtained and schematic drawings were prepared. The right and left brachiocephalic trunks emerged from the aortic arch in 100% of the specimens from the right brachiocephalic trunk origined a common trunk the thyroid arteries, syringotracheal trunk, vertebral artery, superficial lateral cervical artery, basecervical artery, and ascending esophageal artery. The left brachiocephalic trunk collaterally stemmed in the left common carotid artery, which in turn led to the left internal carotid and a common trunk which stemmed the thyroid arteries, the syringotracheal trunk, vertebral artery, superficial lateral cervical artery, basecervical artery and descending esophageal artery. At the end of its trajectory, the right and left brachiocephalic trunks give rise to the right and left subclavian arteries, which in turn, stem the sternoclavicular, axillary, and intercostal arteries, pectoral trunk, cranial pectoral arteries, pectoral caudal artery and collateral branches of the pectoral trunk. Based on the results, it was concluded that the aortic arch in rheas issued right and left brachycephalic trunks.

KEYWORDS: Brachiocephalic trunks. Internal carotid. Ratites. *Rhea americana americana.*

INTRODUCTION

Greater rheas (*Rhea americana americana*) are ratite birds of economic interest with high reproductive potential and production due to the products and by-products that they can provide such as meat, leather, feathers and fat which are in great demand in world markets (ALMEIDA, 2003). According to Dunning and Belton (1993), this species is suitable for breeding in Brazil, given its ease of adapting to captivity and being commonly found in the Northeast, Midwest and Southeast of the country. They are social animals that can live up to 40 years in captivity.

There is research in the literature relating to the vascular morphology of ratites, especially with respect to blood vascularization, such as studies with ostriches about origin and main branches of the celiac artery (NEIRA et al., 2014), on blood systematization of the base of the brain (NAZER; CAMPOS, 2011), and also studies on the arterial vascularization of the cloacal bursa in rheas (OLIVEIRA et al., 2016). However, information about the morphology of the cardiovascular apparatus of rheas is still scarce, especially regarding the aortic arch.

There are many studies that describe the aortic arch vascular morphology of several species of birds. In this context, there are data about the origin, number and distribution of the artery in the heart base in pigeons (GLENNY, 1940), in domestic geese (SANTOS et al., 2006) and in Eurasian bittern (waterfowl) (ERDOGAN, 2012). In the ratites group there have been studies on Kiwis (GLENNY,

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1942a), Cassowaries (GLENNY, 1942b) and on late embryos of rheas (*Rhea americana intermedia)* (GLENNY, 1943a).

Research with arteries of the heart base in birds is important, as these animals develop a primitive circulation formed by the ductus arteriosus (Botalli) when in the embryo stage, consisting of communication between the pulmonary trunk and the aortic arch normally found in embryos (GLENNY, 1943a), however, the persistence of the duct in young and adult animals may lead to serious circulatory problems, as well as other cardiovascular diseases. As such, the description of these vessels in greater rhea is justified in order to promote clinical and surgical assistance to these cardiovascular problems.

Considering the economic, physiological and clinical surgical importance of greater rheas, and in seeking to promote important information for the evolutionary biology of the species and also due to the lack of information in the literature on its cardiovascular apparatus, with this study aimed to describe the collateral branches of the aortic arches in greater rheas. The findings will help to identify and systematize the aortic arches as to the origin and route, thereby contributing to the biology of the specie for interventions related to clinical and surgical procedures involving the structures in question, and to preserve them in captivity, in addition to promoting information on comparative anatomy.

MATERIAL AND METHODS

The bodies of ten young animals (aged between two and three months) and ten adults (aged between twelve and thirteen months), totaling 20 specimens of both sexes were used in this study. They were kept in a freezer at the Multiplication Center of Wild Animals - (CEMAS) of the Universidade Federal Rural do Semi-Árido - (UFERSA), Mossoro-RN, a scientific breeding ground registered with IBAMA (Registration 1478912). It covers an area of 20 ha and is located between the geographic coordinates 5º 11'S and 37º 20'W Gr, with an altitude of around 16 m above sea level. The study was submitted and approved by CEUA before it began (Opinion No. 09/2015, process No. 23091.004968/2015-23).

The animals were thawed and an incision was made in the median plane in the craniocaudal direction in order to expose the thoracic aorta. Then, the aorta was cannulated. The vascular system was rinsed with 0.9% saline solution and then perfused with Neoprene 450 latex (Du Pont do Brasil S.A.) and stained with yellow pigment (Globo S.A. Tintas e Pigmentos) in order to adequately visualize vessels. After the injection of latex, the animals were fixed in 3.7% formaldehyde aqueous solution. After 72 hours, dissections and analysis of vascular structures of the base of the heart were started, then morphometric analysis in order to establish a vascular pattern model, and to identify possible variations. Photographic images (DSC-W570 16.1 MP Sony digital camera) of the aortic arch were obtained of each sample analyzed, as well as preparation of schematic drawings for illustration of the results.

The study was based on nomenclature adopted from the HANDBOOK OF AVIAN ANATOMY: NOMINA ANATOMICA AVIUM (1993) for denomination of the identified structures, and the results were compared with the literature on studies of domestic and wild birds, as well as mammals and reptiles. The results were expressed based on descriptive anatomy and evaluated based on simple percentage calculation.

RESULTS

The aorta originated from the left ventricle in 100% of animals, which forms the emerging aortic arch at the heart base. From this in turn emerges the right and left brachiocephalic trunk (Figure 1). The aortic arch is directed to the right antimere continuing artery and thoracic aorta, and then to the abdominal aorta.

The brachiocephalic trunks (right and left) were present in all samples (100%). Regarding the order of issuance of the brachiocephalic trunks, it was found that the left brachiocephalic trunk emerges in all animals and immediately after the right brachiocephalic trunk arises. It was observed that these arteries emerged one next to the other in most of the animals studied (90%) (Figure 2A), however, a slight variation was observed in two animals; in one animal (5%), a distance of about 0.4 cm from the origin of these arteries (Figure 2B), and 0.9 cm in the other animal (5%) (Figure 2C).

The left brachycephalic trunk had a larger caliber than the right brachiocephalic trunk in all animals analyzed. Regarding their course, a lateral-cranial direction is presented. From the left brachycephalic trunk arise the left common carotid artery which in turn originated to the internal carotid artery, being responsible for the brain blood supply of the greater rhea (Figure 1).

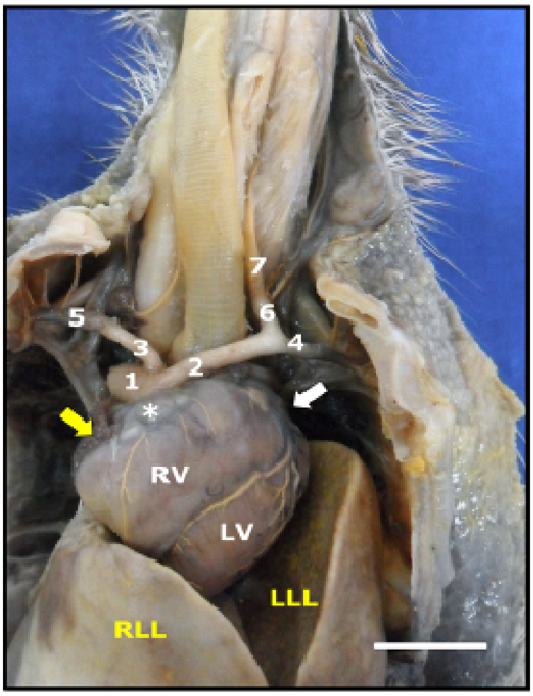

Figure 1. Collateral arteries of the aortic arch in young rhea - Ventral view. Showing the aortic artery (1); left brachiocephalic trunk (2); right brachiocephalic trunk (3); left subclavian artery (4); right subclavian artery (5); common carotid artery (6); internal carotid artery (7); right atrium (yellow arrow); left atrial (white arrow); right ventricle (RV); left ventricle (LV); right auricle (*); right lobe of liver (RLL); left lobe of liver (LLL). Bar: 1 cm. Source: Personal File (2015).

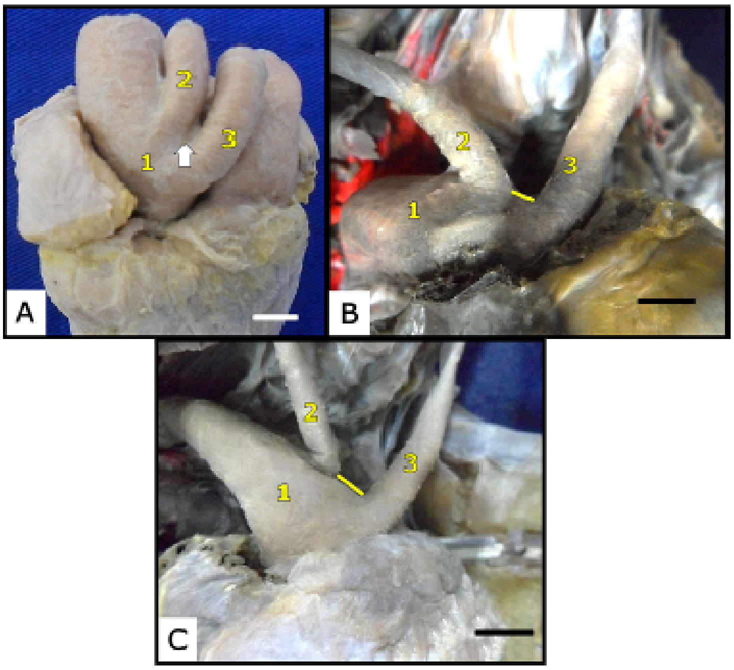

Figure 2. Origin of brachiocephalic trunks in adult rhea - Ventral view. A, B and C showing: aorta artery (1); right brachiocephalic trunk (2); left brachiocephalic trunk (3). In A, the standard model is observed in relation to the origin of the brachiocephalic trunks and there is a very close relationship of both brachiocephalic trunks (white arrow). B, showing anatomical variation in relation to the origin of the brachiocephalic trunks, evidencing the 0.4 cm difference between the origin of the brachiocephalic trunks (yellow bar). In C, showing another anatomical variation in relation to the origin of the brachiocephalic trunks, with 0.9 cm difference in the distance between the origin of the brachiocephalic trunks (yellow bar). Bar: 1 cm. Source: Personal File (2015).

Also arising from the left common carotid artery a common trunk emerges that originates the vertebral, thyroid, superficial lateral cervical, basecervical, and descending esophageal arteries (Figure 3A and 3B) and a common syringotracheal trunk which in turn gives rise to syringeal and tracheal arteries (Figure 3E).

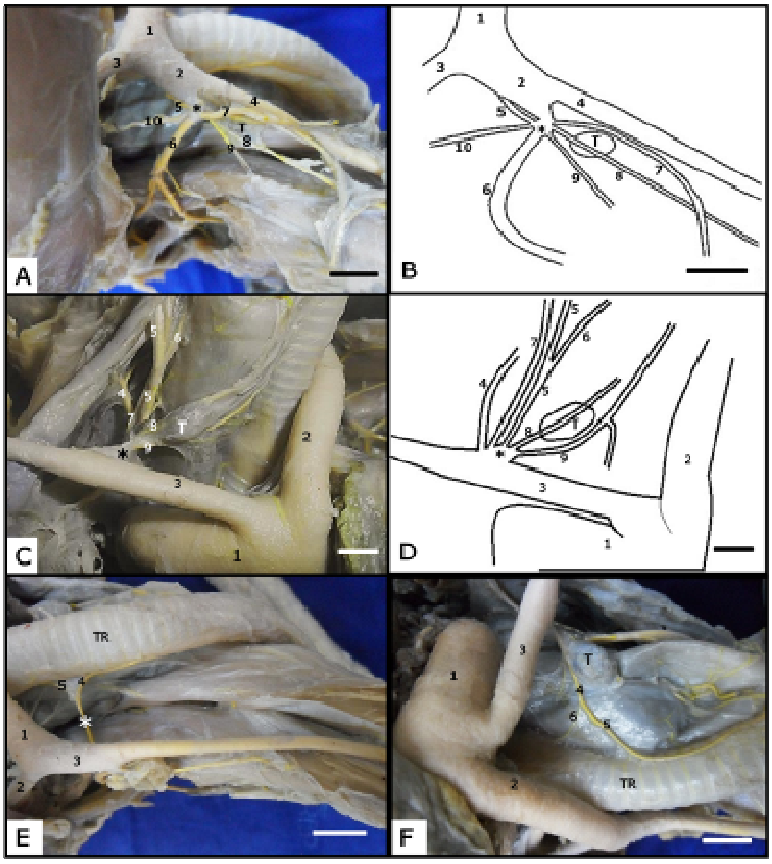

Figure 3. Branches of the collateral arteries of the aortic arch in adult rhea. A and B showing the left brachiocephalic trunk (1); common carotid artery (2); left subclavian artery (3); internal carotid artery (4); left common trunk (*); left syringotracheal trunk (5); left vertebral artery (6); left superficial lateral cervical artery (7); left thyroid artery (8); left basecervical artery (9); left descending esophageal artery (10); left thyroid gland (T). C and D indicating the aortic artery (1); left brachiocephalic trunk (2); right brachiocephalic trunk (3); right common trunk (*); right vertebral artery (4); right superficial lateral cervical artery (5); right ascending esophageal artery (6); right basecervical artery (7); right thyroid artery (8); right syringotracheal trunk (9); right thyroid gland (T). E evidencing the left brachiocephalic trunk (1); left subclavian artery (2); left common carotid artery (3); left syringotracheal trunk (*); left tracheal artery (4); left syringeal artery (5); trachea (TR). F evidencing the aortic artery (1); left brachiocephalic trunk (2); right brachiocephalic trunk (3); right syringotracheal trunk (4); right tracheal artery (5); right syringeal artery (6); right thyroid gland (T); trachea (TR). Bar: 1 cm. Source: Personal File (2015).

In all animals studied, the right brachiocephalic trunk gave off to a common trunk that originated the vertebral, thyroid, superficial lateral cervical, basecervical, and ascending oesophageal arteries (Figure 3C and 3D), as well as a syringotracheal trunk which in turn gave off to syringeal and tracheal arteries (Figure 3F). It is noteworthy that the right common carotid artery does not originate from the right brachiocephalic trunk.

The continuation of the right and left brachiocephalic trunks are called right and left subclavian arteries. Right and left subclavian arteries give off to the sternoclavicular, axillary, and intercostal arteries and pectoral trunk, which in turn originate the pectoral cranial and caudal arteries, as well as several side branches (Figure 4).

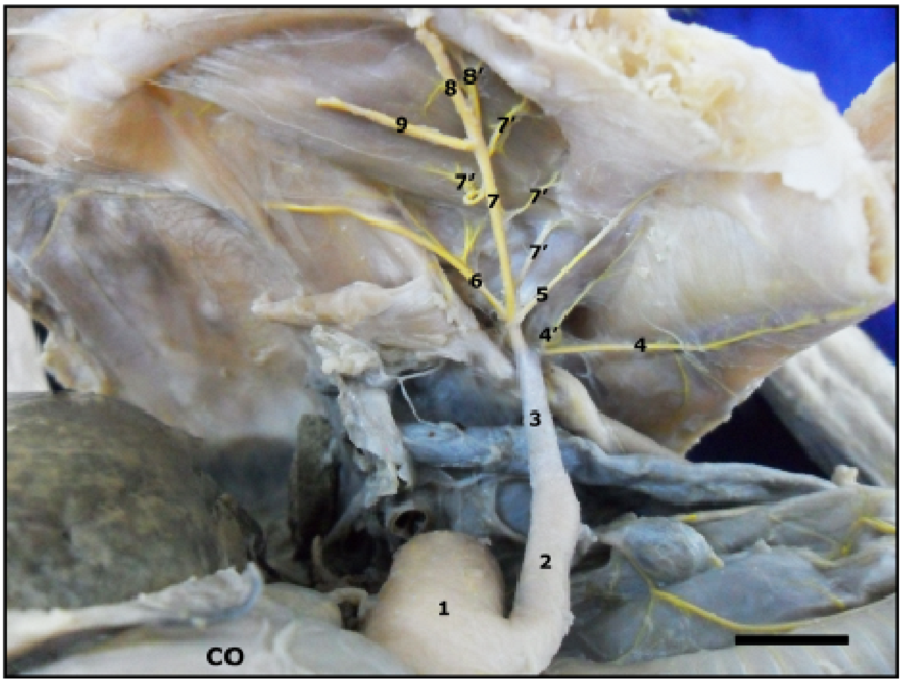

Figure 4. Branches of the right subclavian artery in adult rhea - Ventral view. Evidencing the aortic artery (1); right brachiocephalic trunk (2); right subclavian artery (3); right sternoclavicular arteries (4, 4'); right axillary artery (5); right intercostal artery (6); right pectoral trunk (7); collateral branches of the right pectoral trunk (7'); right cranial pectoral arteries (8, 8'); right pectoral caudal artery (9) and heart (CO). Bar: 1 cm. Source: Personal File (2015).

DISCUSSION

The aorta artery in the greater rhea emerges from the left ventricle, similar to what is observed in the taxon of mammals and birds. Upon arriving at the base of the heart, it forms the aortic arch, a great caliber vessel from which both left and right brachiocephalic trunks collaterally protrude from the aortic arch. This is the same pattern observed by Santos et al. (2006) in studies with domestic geese. In domestic mammals (GHOSHAL, 1981; GETTY, 1986; DYCE; SACK; WENSING, 2010; KÖNIG; LIEBICH, 2011), it has been observed that one brachiocephalic trunk and the left subclavian artery emerge from the aortic arch. We can also cite another model for the collateral aortic arch; the capybara, studied by Culau et al. (2007), where only one brachiocephalic trunk arises from the aortic arch.

A single aortic arch directed towards the right antimere is present in the greater rhea. It emerges in the left ventricle in a median plane and curves to the right at the height of the right brachiocephalic trunk, in the same way as was reported for the group of ratites; ostriches (SOARES; OLIVEIRA; BARALDI-ARTONI, 2010), in kiwis (GLENNY, 1942a), in cassowaries (GLENNY, 1942b) and in late embryos of rheas (*Rhea americana intermedia*) (GLENNY, 1943a), as well as in several orders of birds, such as Coliiformes (GLENNY, 1944a), Passeriformes (GLENNY, 1945a), Charadriiformes (GLENNY, 1947) and Galliformes (GLENNY, 1951a). This arrangement of the aortic arch differs from what is reported in domestic mammals (GHOSHAL, 1981; GETTY, 1986; DYCE; SACK; WENSING, 2010; KÖNIG; LIEBICH, 2011), and wild mammals, such as the chinchilla (ARAÚJO; OLIVEIRA; CAMPOS, 2004), the rock cavy (MAGALHÃES et al., 2007), the galea (*Galea spixii*) (OLIVEIRA et al., 2015), the collared anteater (*Tamandua tetradactyla*) (PINHEIRO et al., 2012), and the gray brocket (*Mazama gouazoubira*) (SCHIMMING et al., 2012), which all have the aortic arch arranged towards the left antimere. On the other hand, reptiles such as the Brazilian tortoise (FARIA; MARIANA, 2001) and the red-eared slider (VOLL; CAMPOS; ARAÚJO, 2014) have two juxtaposed aortic arches, a right and a left, each facing each antimere (one facing left and the other facing the right antimere).

In all examined greater rheas, the left brachiocephalic trunk arises from the aortic arch before the right brachiocephalic trunk, and then is shortly craniolaterally directed, one for each antimere, from the aortic arch. These findings are similar to findings in domestic birds such as hens (KOCH, 1973) and geese (SANTOS et al., 2006), and also in wild birds, such as aracari (SILVA et al., 2009a), maracanã macaws (SILVA et al., 2009b), campo orioles (concriz) (SILVA et al., 2009c), burrowing owls (SILVA et al., 2009d), and roadside hawks (gavião-carijó) (SILVA et al., 2009e). In studying kiwis, cassowaries and greater rhea embryos, Glenny (1942a, 1942b, 1943a) made references to these arteries without naming them. However, when analyzing the schemes drawn by the author, we can conclude that they really refer to the brachiocephalic trunks.

The main feature of the arterial pattern in the neck of ratites is the presence of a single internal carotid artery. Birds that show this type of arrangement are called laevocarotidinae, a classification made by Garrod (1873) and Beddard (1898) in studying various bird orders. This vascular pattern in which animals display only a singular internal carotid artery was described in Piciformes (GLENNY, 1943b), Coliiformes (GLENNY, 1944a) and Passeriformes (BEDDARD, 1898; GLENNY, 1945a). By contrast, birds which have two internal carotid arteries in the neck are called bicarotidinae, examples of which are noted in Charadriiformes (GLENNY, 1947), Galliformes (GLENNY, 1951a), Sphenisciformes (GLENNY, 1944b), Psittaciformes (GLENNY, 1951b) and Gruiformes (GLENNY, 1945b).

It was found that the right and left subclavian artery in greater rheas derive from the right and left brachiocephalic trunks, respectively, which are laterally arranged similar to what was observed in aracari (SILVA et al., 2009a), roadside hawks (SILVA et al., 2009e) and campo orioles (SILVA et al., 2009c). In greater rheas, the (right and left) subclavian arteries stem the sternoclavicular, axillary, and the intercostal arteries and the pectoral trunk which in turn originated the pectoral cranial and pectoral caudal arteries, and also several collateral branches. These results corroborate the reported in domestic geese (SANTOS et al., 2006), in which it was observed that the sternoclavicular, axillary and intercostal arteries, and (inconsistently) the incidental sternoclavicular arteries and pericardial branches all stemmed from the subclavian artery.

Regarding the origin and distribution of the arteries derived from large vessels in greater rheas, it was observed that the right brachiocephalic trunk gave off to the vertebral artery, thyroid artery, superficial lateral cervical artery, basecervical artery, ascending esophageal artery and a syringotracheal common trunk. On the left antimere, it was found that the spinal artery, thyroid artery, superficial lateral cervical artery, basecervical artery, descending esophageal artery, syringotracheal trunk and internal carotid stemmed from the left common carotid. In studies with kiwis on the other hand, Glenny (1942a) found that the scapular artery, shawii duct, cervico-brachial-scapular artery, ascending esophageal artery and lymphatic artery stemmed from the right internal carotid artery, while the scapular artery, shawii duct, ascending tracheo-lymphatic artery, vertebral artery and superficial cervical artery emerged from the left internal carotid artery. Likewise, Glenny (1943a) in studying late embryos of greater rheas described that the syringotracheal arteries, shawii duct, thyroid artery, vertebral artery, ascending esophageal artery and superficial lateral cervical artery stemmed from the right common carotid artery, and syringotracheal arteries, shawii duct, thyroid artery, vertebral artery, superficial lateral cervical artery and internal carotid came from the left common carotid.

In general, for birds (KOCH, 1973; SCHWARZE; SCHRODER, 1980; BAUMEL, 1993), pigeons (BHADURI; BISWAS, 1954; BHADURI; BISWAS; DAS, 1957) and hens (SCHWARZE; SCHRODER, 1980; GETTY, 1986), the sternoclavicular artery has been found to be a collateral branch of the subclavian artery, responsible for the vascularization of the sternum and clavicle. This result was similar to the present study in greater rheas. However, this was different from what was reported by Glenny (1942a, 1942b, 1943a) in studies with kiwis, cassowaries and in greater rhea embryos, respectively, which did not describe the sternoclavicular artery.

In studies conducted with geese (SANTOS et al., 2006) and in greater rhea embryos (GLENNY, 1943a), it was observed that the intercostal and axillary arteries participate in the supply blood to the thoracic region, corroborating the findings in this study of greater rheas. Glenny (1942a) described a single intercostal artery in kiwis, while in cassowaries (GLENNY, 1942b) the presence of two intercostal arteries (ventral and lateral) was observed; however, when considering the origin of the axillary artery in kiwis and in cassowaries, they originated from the right and left pectoral artery, while in the greater rheas of this study they originated from the right and left subclavian arteries.

This study observed that pectoral trunks emerge from the final portion of the subclavian arteries, and each of them then give rise to three pectoral arteries, being two cranial and one caudal, which follow a short and straight lateral path, destined to vascularize chest muscles and the forelimbs. These results differ from what was reported by Baumel (1993) in *Gallus gallus*, by

Santos et al. (2006) for domestic geese, and by Glenny (1943a) for greater rhea embryos, which reported that each pectoral trunk branches off into two pectoral arteries; one cranial and another caudal. In contrast, Glenny (1942a) himself described that the terminal branch of the subclavian artery in Kiwis stems as pectoral artery rather than pectoral trunk, and the branches derived from this artery were referred to as axillary branches and cutaneous branch. For pigeons, Bhaduri and Biswas (1954) and Bhaduri, Biswas and Das (1957) mention the participation of a third vessel arising from the pectoral trunk, called the pectoral artery, which was not observed in our study with greater rheas. This can probably be explained due to the greater rhea not having the ability to fly and thus having a smaller supply of blood vessels in their wings, while pigeons fly, thereby requiring greater vascularization.

CONCLUSION

The aortic arch in rheas issued right and left brachycephalic trunks. Furthermore, it was found that the greater rheas only have a left internal carotid artery, thus being classified as laevocarotidinae birds.

RESUMO: A ema (*Rhea americana americana*) é uma ave da família Rheidae e por isto denominada de ratita, por não apresentar aptidões para o voo. Este animal tem grande potencial reprodutivo e produtivo, em função dos produtos e subprodutos que podem fornecer como carne, couro, penas e gordura muito procurados no mercado mundial. Dada a sua importância econômica e pela falta de informação na literatura sobre sua morfologia, principalmente no que diz respeito ao seu aparelho cardiovascular, objetivou-se descrever os ramos colaterais do arco aórtico, de modo a estabelecer a origem e distribuição destas artérias e, assim, contribuir com informações para a biologia da espécie. Foram utilizadas 20 emas jovens e adultas de ambos os sexos, oriundas do CEMAS/UFERSA, as quais vieram a óbito por causas naturais e que se encontravam armazenadas em freezer. A experimentação foi aprovada pela CEUA/UFERSA (Parecer n° 09/2015, processo n° 23091.004968/2015-23). Os animais foram descongelados e tiveram a artéria aorta torácica canulada e o sistema vascular perfundido com látex Neoprene 450 corado com pigmento amarelo. Posteriormente, os animais foram fixados em solução aquosa de formaldeído a 3,7% e após 72 horas realizaram-se as dissecações e obtenção de imagens fotográficas e elaboração de desenhos esquemáticos. Em 100% dos espécimes, emergiram a partir do arco aórtico os troncos braquiocefálicos direito e esquerdo. O tronco braquiocefálico direito emitiu colateralmente a partir de um tronco comum as artérias tireoide, tronco siringotraqueal, vertebral, cervical superficial lateral, basecervical e esofageana ascendente. Já o tronco braquiocefálico esquerdo emitiu colateralmente a artéria carótida comum esquerda, que por sua vez, originou a carótida interna esquerda e um tronco comum que emitiu as artérias tireoide, tronco siringotraqueal, vertebral, cervical superficial lateral, basecervical e esofageana descendente. No final de seu percurso, os troncos braquiocefálicos direito e esquerdo, originaram as artérias subclávias direita e esquerda, que por sua vez, emitiram as artérias esternoclaviculares, axilar, intercostal, tronco peitoral, peitorais craniais e peitoral caudal e ramos colaterais do tronco peitoral. Com base nos resultados, concluiu-se que, em emas, o arco aórtico emitiu os troncos braquicefálicos direito e esquerdo.

PALAVRAS-CHAVE: Troncos braquiocefálicos. Carótida interna. Ratitas. *Rhea americana americana.*

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