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Radan Elvis Matias de Oliveira
Universidade Federal Rural do Semi-Árido - UFERSA

Fernanda Attademo
Centro de estudos e Monitoramento Ambiental

Flavio José de Lima Silva
Universidade do Estado do Rio Grande do Norte (UERN)

Simone Almeida Gavilan
Universidade Federal do Rio Grande do Norte

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Angioarchitecture of collateral arteries of the aortic arch of Antillean manatee (*Trichechus manatus manatus* Linnaeus, 1758)

Radan Elvis Matias de Oliveira[1,2,3,4] | **Giovanna Almeida Santoro[2,3]** | **Augusto Carlos da Bôaviagem Freire[2,4]** | **Fernanda Löffler Niemeyer Attademo[2,4]** | **Stella Almeida Lima[2,3,4]** | **Aline da Costa Bomfim[2,3,4]** | **Ana Bernadete Lima Fragoso[2]** | **Flávio José de Lima Silva[2,4]** | **Simone Almeida Gavilan[2,3,4]** | **Moacir Franco de Oliveira[1]**

[1]Applied Animal Morphophysiology Laboratory, Department of Animal Sciences, Federal Rural University of Semi-Árido – UFERSA, Mossoró, Brazil

[2]Cetáceos da Costa Branca Project, University of the State of Rio Grande do Norte – PCCB-UERN, Mossoró, Brazil

[3]Vertebrate Morphophysiology Laboratory, Department of Morphology, Federal University of Rio Grande do Norte – UFRN, Natal, Brazil

[4]Center for Environmental Studies and Monitoring – CEMAM, Areia Branca, Brazil

Correspondence
Radan Elvis Matias de Oliveira, Applied Animal Morphophysiology Laboratory, Department of Animal Sciences, Federal Rural University of Semi-Árido – UFERSA, Mossoró-RN, Brazil.
Email: radan_elvis@hotmail.com

Abstract

The aortic arrangement is an important structure associated with the maintenance of homeostasis. Based on this information, this study was conducted to describe the collateral arteries of the aortic arch of Antillean manatee and define the standard model for the species. Three specimens, an adult male, adult female and a male neonate, all strandings on the coast of the state of Rio Grande do Norte, Brazil, were used. The study was performed in the Laboratory of Morphophysiology of Vertebrates of the Federal University of Rio Grande do Norte, where in situ photographs were taken to demonstrate their topography. Subsequently, their hearts were removed and fixed in 10% formaldehyde and after 72 hr were dissected and analysed, obtaining schematic drawings and photographs of the vascular arrangement. The aortic arch was represented by three collateral arteries identified as the brachiocephalic trunk, left common carotid artery and left subclavian artery. This arrangement was similar to that found for other sirenians, and yet, for other mammals like hooded seal, murine, margarita island capuchin, black-handed tamarin, Mongolian gerbil and human. The morphological similarity presented in this study with different species of mammals, including humans, may contribute valuable information from an evolutionary point of view.

KEYWORDS

aortic bulb, cardiovascular system, collateral branches, marine mammal, sirenians

1 | INTRODUCTION

Sirenians are the only existing herbivorous aquatic mammals, which make them evolutionarily different from other mammals. This taxonomic group is represented by only four living species, the Manatee (*Trichechus manatus*), Amazonian manatee (*Trichechus inunguis*), African manatee (*Trichechus senegalensis*) and Dugong (*Dugong dugon*) (Hartman, 1979). A fifth representative of the group, the Steller's sea cow (*Hydrodamalis gigas*) was extinct in the mid-18th century (Anderson, 1995; Forsten & Youngman, 1982).

The distribution of the manatee is limited to a portion of the west coast of the Atlantic Ocean, with records of two subspecies, the Florida manatee (*Trichechus manatus latirostris*) in North America and the Antillean manatee (*Trichechus manatus manatus*) existing throughout Central and South America (Domning & Hayek, 1986). The manatee is classified as a threatened species (Iucn, 2008) and is in danger of extinction according to the list of endangered species of Brazil (Luna, Balensiefer, Fragoso, Stephano, & Attademo, 2018).

The current conservation scenario, together with their biological characteristics, raises concern with the future of this species in Brazil (Balensiefer et al., 2017). The knowledge of the biology and ecology of Sirenians is growing, but information on the morphology of the cardiovascular system is still scarce. Pioneering studies have been published describing the heart morphology of the Dugong and Florida manatee (Rowlatt & Marsh, 1985). However, information on the morphology of the cardiovascular system of the subspecies *Trichechus manatus manatus* is still lacking, which is important regarding the point of view of conservation and the knowledge of their morphology.

The cardiovascular system of aquatic mammals is quite differentiated due to the physiological adaptation to diving developed by these animals (Drabek, 1975; Howard, 1983, p. 12). Therefore, a solid understanding of the circulatory system is an important prerequisite for the correct interpretation of cardiovascular diseases in these species. According to Gerlach et al. (2013), the *ante-mortem* diagnosis of some cardiovascular diseases in manatees is possible through an echocardiographic evaluation. Thus, detailed anatomical descriptions of the aortic arch of the Antillean manatee are indispensable. Moreover, such descriptions may also be useful in toxicological studies, since numerous chemicals, including some drugs, may produce aortic arch malformations (Monnereau et al., 2005). Anatomical studies also provide information regarding the diagnosis and clinical treatment of diseases by means of complementary tests such as Doppler echocardiography and contrast radiography (Bortolini et al., 2013; Cabral, Ciasca, Oliveira, Vaz-Curado, & Larsson, 2010).

Thus, considering the importance that the cardiovascular system represents for physiological adaptation to diving for manatees, in addition to the scarcity of data on the morphology of the aortic arch, and knowing that the manatee is one of the most threatened marine mammals in terms of extinction, the aim of this study was to describe the collateral arteries of the aortic arch of the species *Trichechus manatus manatus* and define the standard model for the species.

2 | MATERIALS AND METHODS

Three specimens of free-living Antillean manatee found dead on the beach were used in the study: an adult male (total length: 313.5 cm), an adult female (total length: 290.0 cm) and a male neonate (total length: 123.0 cm). The experiment was developed with authorisation from the Ethics Committee on Animal Use (License No. 020/2009, Protocol 23083.006846/2009), and the animals were stranded on the coast of the state of Rio Grande do Norte, Brazil, between Sagi (06°29′10.2″S, 34°58′07.6″W) and Tibau (4°49′56.3″S, 37°15′09.8″W), bordering the States of Paraíba (PB) and Ceará (CE; Figure 1).

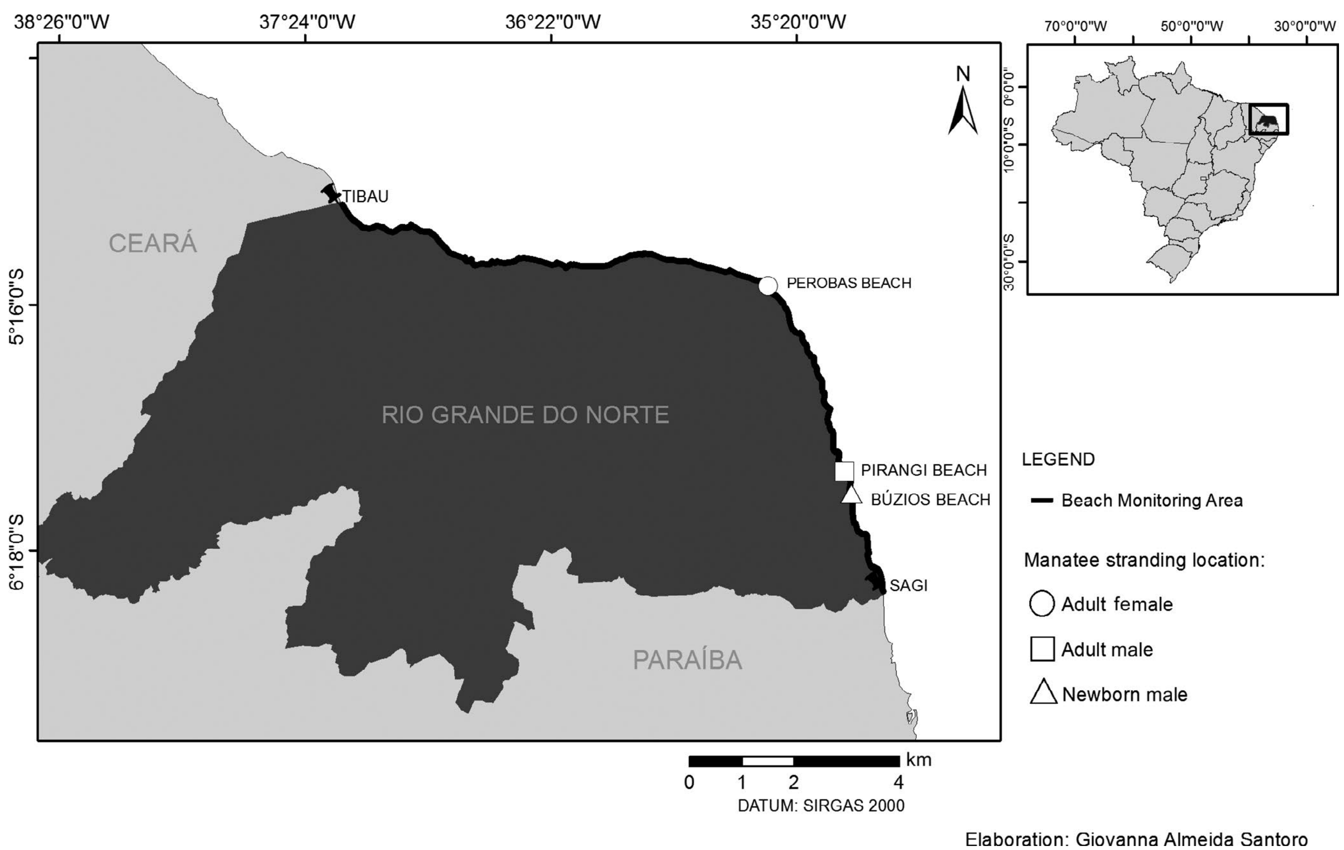

FIGURE 1 Map of the monitoring area of beaches of the Project *Cetáceos da Costa Branca* and the stranding locations of the animals of the study

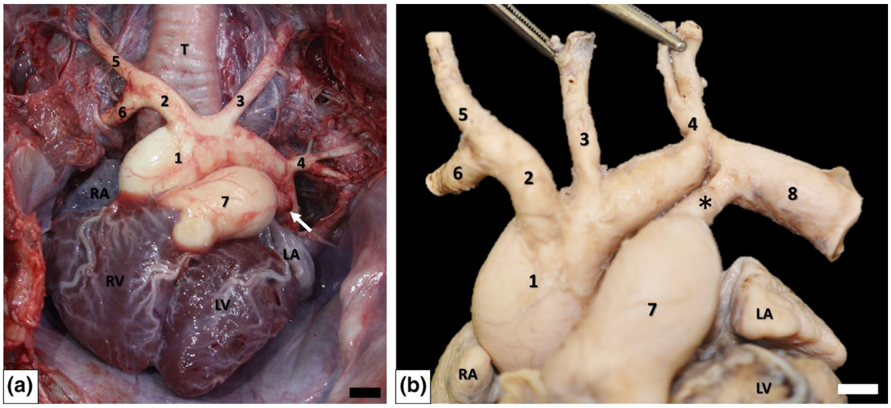

FIGURE 2 Aortic arch of the Antillean manatee neonate and its collateral arteries, ventral view. (a) The aortic arch in situ, forming a bulb before the collateral arteries (1), the brachiocephalic trunk (2), the left common carotid artery (3), left subclavian artery (4), right common carotid artery (5), right common carotid artery (6), pulmonary trunk (7), ductus arteriosus (arrow), right atrium (RA), left atrium (LA), right ventricle (RV), left ventricle (LV) and trachea (T). In (b), the same formalised anatomical piece, showing the aortic arch (1), the brachiocephalic trunk (2), left common carotid artery (3), left subclavian artery (4), right common carotid artery (5), right subclavian artery (6), pulmonary trunk (7), descending aorta (8), ductus arteriosus (*), right atrium (RA), left atrium (LA) and left ventricle (LV). (Bar: 1 cm)

The animals were registered by the team of the Project for Monitoring the Beach of the *Cetáceos da Costa Branca* Project—University of the State of Rio Grande do Norte (PCCB-UERN). The necroscopic examinations were carried out in the Laboratory of Morphophysiology of Vertebrates of the Federal University of Rio Grande do Norte, where photographs were taken in situ to demonstrate the topography of the aortic arch. The heart was then removed and fixed in 10% formaldehyde. After 72 hr, the samples were dissected and analysed, obtaining schematic drawings and photographs of the angioarchitecture of the aortic arch.

The study was based on the nomenclature adopted by the International Committee on Veterinary Gross Anatomical Nomenclature (2017) for the names of the structures identified and the results compared with published studies with other marine mammals, other domestic and wild mammals, as well as with humans.

3 | RESULTS

The vascular arrangement of aortic arch of the Antillean manatee was common to all the specimens studied, without any variation between them. From the aortic arch, the brachiocephalic trunk, left common carotid artery and the left subclavian artery emerge as collateral arteries. The brachiocephalic trunk, in all animals studied, forked in two branches, the right common carotid artery and the right subclavian artery.

In all specimens, the ascending aorta presented a dilatation that extended up to the origin of the brachiocephalic trunk, called the aortic bulb, which has a visibly larger diameter in relation to the descending aorta. In the adult male, this difference between the outer diameter of the aortic bulb and the descending aorta was 122.22%, being 83.33% in the female and 106.66% in the neonate. Furthermore, an open ductus arteriosus was observed in the neonate, originating from the pulmonary trunk, communicating with the aortic arch soon after the origin of the left subclavian artery (Figure 2).

4 | DISCUSSION

The collateral branches of the aortic arch of aquatic mammalian species, terrestrial mammals (domestic and wild) and humans have been described in studies that characterise the main arteries that emerge directly from the arch, their branches and thus, classify the different types of vascular arrangements of the aortic arch for each species (Oliveira et al., 2018).

Three different types of arrangements have been described more often (Figure 3). The first type corresponds only to the brachiocephalic trunk arising from the aortic arch and from the right and left common carotid arteries and the right and left subclavian arteries arise. This type has already been described in the laboratory rat (*Rattus norvegicus*; Hebel & Stromberg, 1986), buffalo (*Bubalus bubalis*; Cortellini, Machado, Oliveira, Miglino, & Artoni, 2000), capybara (*Hydrochoerus hydrochaeris*; Culau, Reckziegel, Lindemann, Araújo, & Balzaretti, 2007), grey brocket (*Mazama gouazoubira*; Schimming, Matteis, Silva, & Guazzelli Filho, 2012), domestic cow (*Bos taurus*) and horse (*Equus ferus caballus*; Dyce, Sack, & Wensing, 2010, p. 1585).

The second type is characterised by the emergence of two arteries. The first is constituted by the brachiocephalic trunk and the second is formed by the left subclavian artery. The right common carotid artery and left and right subclavian arteries emerge from the brachiocephalic trunk. This arrangement was reported in the southern-fur-seal (*Arctocephalus australis*; Guimarães, Mari, Le Bas, & Watanabe, 2014), while in the majority of terrestrial species studied, it predominated in rodents such as the paca (*Agouti paca*; Oliveira, Machado, Miglino, & Nogueira, 2001), long-tailed chinchilla

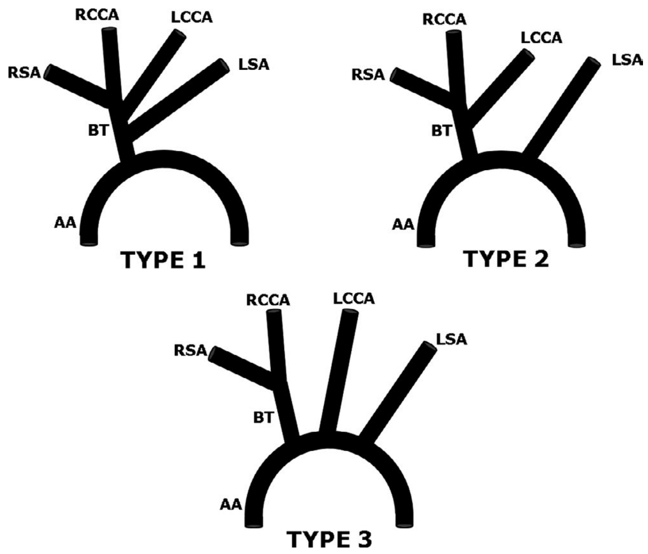

FIGURE 3 Illustration is representative of the three types of arrangements of collateral arteries of the aortic arch more frequently found in marine mammals, terrestrial mammals (domestic and wild), and humans: aortic arch (AA), brachiocephalic trunk (BT), right common carotid artery (RCCA), left common carotid artery (LCCA), right subclavian artery (RSA) and left subclavian artery (LSA)

(*Chinchilla lanigera*; Araújo, Oliveira, & Campos, 2004; Özdemir, Çevik-Demirkan, & Türkmenoğlu, 2008), guinea-pig (*Cavia porcellus*; Kabak & Haziroglu, 2003), rock cavy (*Kerodon rupestris*; Magalhães, Albuquerque, Oliveira, Papa, & Moura, 2007), coypu (*Myocastor coypus*; Campos, Araújo, & Azambuja, 2010) and the spix's yellow-toothed cavy (*Galea spixii*; Oliveira et al., 2015).

The Antillean manatee falls within the third type, where three collateral arteries of the aortic arch emerge, the brachiocephalic trunk, left common carotid artery and the left subclavian artery, and the right common carotid artery and right subclavian artery emerge from the brachiocephalic trunk. This vascular model was also described in the hooded seal (*Cystophora cristata*; Drabek & Burns, 2002), humans (Demertzis et al., 2010; Silva, Pereira, Albuquerque, Teixeira, & Oda, 2012), mice (*Mus musculus*; Casteleyn et al., 2010), black-handed tamarin (*Saguinus niger*; Balensiefer et al., 2017), margarita island capuchin (*Sapajus apella*; Furtado, Vasconcelos, Branco, & Lima, 2017) and the Mongolian gerbil (*Meriones unguiculatus*; Oliveira et al., 2018). The figures and illustrations of Rowlatt and Marsh, (1985) show that the dugong and Florida manatee also fit into this vascular architecture, however the authors did not describe the brachiocephalic trunk.

According to the descriptions published by Silva et al. (2012) there are variations in the arrangement of the aortic arch in humans, with at least four types already described (A, B, C and D). Type A is the most frequently found, composed by the brachiocephalic trunk, followed by the left common carotid artery and the left subclavian artery, with the same arrangement observed in the Antillean manatee. Type B is characterised by the appearance of the left common carotid artery near the origin of the brachiocephalic trunk. In type C, the left common carotid artery arises from the brachiocephalic trunk, as well as the right subclavian artery and right common carotid artery. Finally, type D presents an expressive alteration due to the absence of the brachiocephalic trunk, therefore, the two carotid arteries and the two subclavian (right and left) arises directly from the aortic arch.

Regarding the aortic bulb observed in the specimens of this study, there could be a correlation between the size of the bulb and the diving habits of aquatic mammals with this peculiarity, as animals of more superficial waters have a smaller aortic bulb than deepwater animals (King, 1983, p. 178). Blood pressure is maintained by increasing the amount of elastic tissue present in the aortic bulb, thereby maintaining adequate pressure in the coronary system ensures oxygenation of the heart tissue. These characteristics are anatomical and physiological adaptations to depth, frequency and length of time of dives. Accordingly, the dilation of the aortic bulb supposedly maintains the arterial blood pressure, the perfusion of the brain and the cardiac tissue during bradycardia (Drabek, 1975).

In some species of terrestrial mammals such as the European brown hare (*Lepus europaeus*; Brudnicki, Macherzyńska, & Nowicki, 2007), the rock cavy (Magalhães et al., 2007), pig (*Sus scrofa domesticus*; Konig & Liebich, 2016, p. 788) and the southern tamandua (*Tamandua tetradactyla*; Pinheiro, Lima, Pereira, Gomes, & Branco, 2012), a common trunk is observed which creates the right and left common carotid arteries, called a bicarotid trunk. This arrangement is a standard structure in these species, but it can be observed in other species of animals as a variation, for example in 10% of spix's yellow-toothed cavy (Oliveira et al., 2015). This structure was not observed in manatees, since in these animals, the left common carotid artery arises directly from the aortic arch, making it impossible to approach the right common carotid artery in the brachiocephalic trunk.

A second trunk called the brachiocarotid was reported in capybaras by Culau et al. (2007), which gives rise to the right common carotid and right subclavian arteries. This trunk originates from the brachiocephalic trunk, and this structure was also observed in some species, such as the paca (Leal et al., 2017; Oliveira et al., 2001), ocelot (*Leopardus pardalis*; Martins et al., 2010) and the New Zealand rabbit (*Oryctolagus cuniculus*; Souza, Bavaresco, & Campos, 2013), but the authors do not call it a brachiocarotid trunk but rather the common trunk for the right common carotid artery and right subclavian artery. This angioarchitecture was not observed in the animals studied herein.

An experimental study conducted by Hara et al. (2010), with adult rhesus monkeys (*Macaca mulatta*), showed the degree of impairment of the nervous tissue, specifically the loss of hippocampal cells in relation to the blood supply by the collateral arteries to the aortic arch. Through histological analyses using the Nissl staining, they verified that animals with two of the three connected arterial branches that were clamped had a partial loss of cells and minimal alteration in the number of cell layers in the hippocampal region when compared to clamping of the three branches, resulting in cell death of the hippocampus. This study shows the physiological importance of the three vascular collateral arteries of the aortic arch in animals, such as the hooded seal (Drabek & Burns, 2002), humans (Demertzis et al., 2010; Silva et al., 2012), mice (Casteleyn et al., 2010), black-handed tamarin (Branco et al., 2017), margarita island capuchin (Furtado et al., 2017), the Mongolian gerbil (Oliveira et al., 2018) and the animals studied herein. This feature reduces the consequences of neurological function in cases of natural obstruction of some of these vessels.

5 | CONCLUSION

Three collateral branches of the aortic arch of Antillean manatee were observed, represented by the brachiocephalic trunk, left common carotid artery, and left subclavian artery. This arrangement was similar to that found for other sirenians, and yet, for other mammals like hooded seal, murine, margarita island capuchin, black-handed tamarin, Mongolian gerbil and human. The morphological similarity presented in this study with different species of mammals, including humans, may contribute valuable information from an evolutionary point of view.

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CONFLICT OF INTEREST

The authors declared no potential conflicts of interest concerning the research, authorship and publication of this article.

ORCID

Radan Elvis Matias Oliveira https://orcid.org/0000-0002-0370-4447

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