

MORPHOLOGY OF THE BRAIN BASE ARTERIES OF THE GIANT ANTEATER (*Myrmecophaga tridactyla*)

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Abstract

This study aimed to describe the brain base arteries of the *Myrmecophaga tridactyla* using ten cadavers of adults from this species, including five male and five female specimens. The arterial vascular bed was perfused via the thoracic aorta with a dyed natural latex solution, and the animals were fixed and preserved with a 10% formaldehyde buffered solution. The encephala were removed, and their vessels dissected. Basilar artery formation occurred by anastomosis of the thick ventral spinal artery with vertebral arteries. The basilar artery formed two arterial islands and gave bulbar and pontine branches, and cranial, middle, and caudal cerebellar arteries and ended by forking into its terminal branches, the caudal communicating arteries. The blood supply of the encephalon derived solely from the vertebrobasilar system, and the arterial circle of the brain was closed caudally and rostrally. The absence of participation of internal carotid arteries in encephalon irrigation, the island formations by the basilar artery, and the fusiform shape of the arterial circle of the brain are peculiar characteristics of the vascular anatomy of the brain base of *M. tridactyla*.

Keywords: Brain. Irrigation. Myrmecophagidae. Xenarthra.

1. Introduction

Myrmecophaga tridactyla is a member of the Xenarthra superorder, which includes other anteaters such as *Tamandua tetradactyla* and *Cyclopes didactylus*, armadillos, and sloths. The term Xenarthra derives from an additional and atypical joint in the lumbar vertebrae (Delsuc et al. 2001).

Several species have been studied regarding encephalon base irrigation and arterial circle formation because of a hypothetical correlation to the phylogenetic evolution of the brain (De Vriese 1905). Also, brain irrigation and arterial circle formation vary considerably among species, especially concerning blood supply sources and arterial arrangement multiplicity in this region (Ferreira and Prada 2005; Moraes et al. 2014). This unusual anatomical variety has instigated researchers to explore anatomical behavior further (Ferreira and Prada 2005).

The anatomy of brain irrigation is well-known in domestic animals (Melo and Prada 1998; Schaller et al. 1999, Brundnicki 2000; Campos et al. 2003; Ferreira and Prada 2005; Lima et al. 2006; Moraes et al.

2014) and numerous wild animal species (Reckziegel et al. 2001; Aydin 2005; Aydin et al. 2008, 2009; Ferreira and Prada 2009; Lindemann et al. 2000; Barreiro et al. 2012; Azambuja et al. 2018). However, among individuals of the Xenarthra superorder, it has only been investigated in *Tamandua tetradactyla* (Lima et al. 2013). Therefore, this study is essential to explain and compare the phylogenetic development of brain base arteries in xenarthrans. Also, understanding brain irrigation can help clinicians and veterinary radiologists interpret the increasingly modern imaging tools (Farha et al. 2021), thus contributing to the treatment of injured animals.

This study aimed to describe the brain base arteries of the *Myrmecophaga tridactyla*.

2. Material and Methods

This study used ten adult giant anteater specimens, including five males and five females. The cadavers were donated by the Wild Animals Triage Centers (*Centro de Triagem de Animais Silvestres – CETAS*) of Goiânia, GO, Brazil. The Ethics Committee on the Use of Animals of the Federal University of Goiás (UFG) approved the research project (CEUA-UFG, 018/2014).

The animals were thawed at room temperature, and the thoracic aorta was accessed via the fifth left intercostal space. The vessel was perfused with 2% aqueous saline solution until clearing the vascular bed, and an aqueous latex solution (Altamira™) stained with red dye (Prograf™) was subsequently injected into the vessel. The corpses were fixed with a 10% formaldehyde buffered solution by tissue and body cavity infiltrations with syringes and preserved in the same fixation solution.

The common carotid artery branches were dissected. The encephalon, part of the cervical spinal cord, and its meninges were removed after eliminating the dorsolateral wall of the skull and the vertebral arches from C1 to C3 using an anatomical saw, chisel, and pliers. The dura mater, arachnoid mater, and pia mater were dissected to expose the vessels.

The terminology agreed with the *Nomina Anatomica Veterinaria* (ICVGAN, 2017). The results were documented with a Canon EOS 80D camera.

The data were descriptively analyzed as simple percentages.

3. Results

Basilar Artery

The basilar artery (Figure 1C) was the direct continuation of the ventral spinal artery after receiving the vertebral arteries about 1 cm caudally to the foramen magnum. After entering the cranial cavity, the basilar artery bifurcated twice into parallel collateral vessels of equal caliber, forming, in 100% of anatomical pieces, two arterial islands interconnected by a single artery segment (Figure 1D). The caudal island emitted numerous bulbar branches and the caudal cerebellar artery. The rostral island and the single segment provided several pontine branches and the middle cerebellar artery. At the interpeduncular fossa level, the basilar artery emitted its terminal branches, the caudal communicating arteries (Figure 1I).

Arterial circle

The arterial circle had a fusiform shape extending from the caudal portion of the mesencephalon to olfactory peduncles, with the tuber cinereum and the optic chiasm at its center. The caudal portion consisted of caudal communicating arteries and the rostral portion included rostral cerebral arteries and the small rostral communicating branch from anastomosis of rostral cerebral arteries, and the circuit closed rostrally in all cases. The main vessels from the arterial circle were the rostral cerebellar, caudal, and middle cerebral arteries, and the sphenoid and internal ethmoidal arteries.

Rostral cerebral arteries represented the rostral continuation of caudal communicating arteries after the origin of the middle cerebral artery (Figure 1O) instead of a branch of the internal carotid artery. When the arterial circle would receive internal carotid arteries, it sent sphenoid arteries, which ventrally

crossed two large foramina in the sphenoid wings and produced small branches that anastomosed with small branches of the maxillary artery caudally to the orbits.

The internal carotid artery was not observed in the animals of this study. The common carotid artery was divided into three major branches: facial, occipital, and external carotid arteries (Figure 2). The lingual artery does not originate in this region due to the caudal topography of the tongue root. After originating the inferior alveolar artery, the maxillary artery gave rise a branch that turned caudally and crossed the lateral wall of the tympanic bulla (Figure 2B). Then, it entered the occipital wall and branched into the dura mater caudally to the cerebellum. There was no epidural rete mirabile.

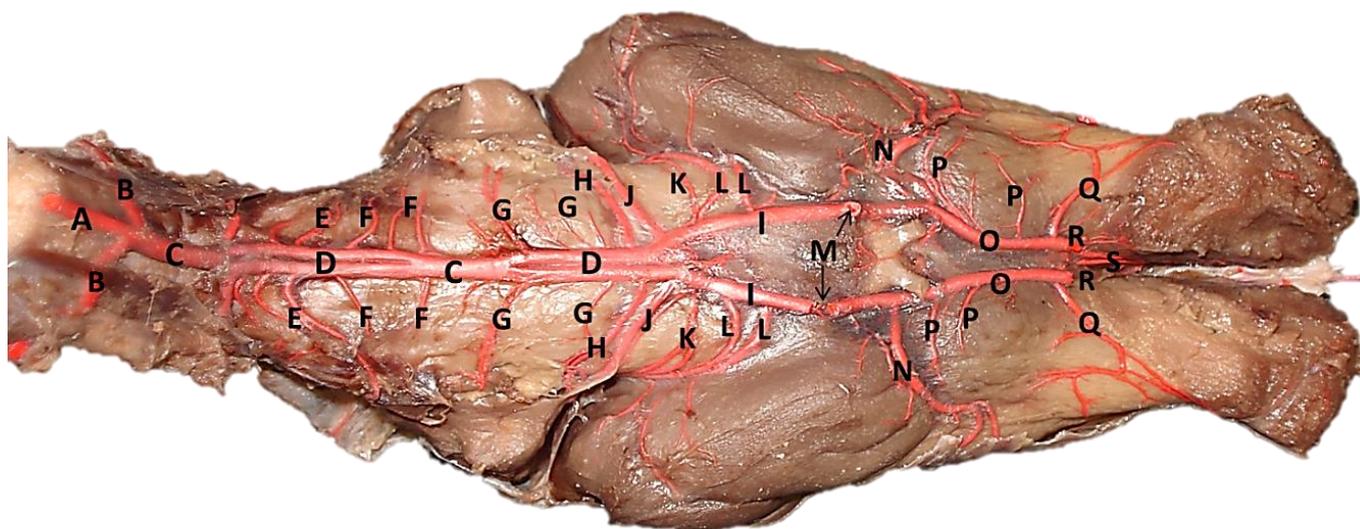


Figure 1. Ventral view of the brain base arteries of *M. tridactyla*. A. Ventral spinal artery; B. Vertebral arteries; C. Basilar artery; D. Basilar artery islands; E. Caudal cerebellar arteries; F. Bulbar branches; G. Pontine branches; H. Middle cerebellar arteries; I. Caudal communicating arteries; J. Rostral cerebellar arteries; K. Caudal choroidal arteries; L. Caudal cerebral arteries; M. Origin of sphenoidal arteries; N. Middle cerebral arteries; O. Rostral cerebral arteries; P. Olfactory tubercle branches; Q. Olfactory bulb arteries; R. Internal ethmoidal arteries; S. Rostral communicating arteries.

Cerebellar arteries

The caudal, middle, and rostral cerebellar arteries showed up in 100% of brain specimens. The rostral cerebellar artery was the thickest and emerged from caudal communicating arteries (Figure 1J), crossed the cerebral peduncles laterally, and distributed on the lateral surface of the cerebellum.

The middle cerebellar artery ascended from the rostral island of the basilar artery slightly caudal to the caudal communicating artery formations and followed laterally and dorsally to distribute on the dorsolateral surface of the cerebellum (Figure 1H).

The caudal cerebellar artery originated from the middle of the caudal arterial island of the basilar artery and ran laterodorsally to ramify into the caudal portion of the cerebellum (Figure 1E).

Cerebral Arteries

The rostral cerebral arteries formed the laterorostral portion of the arterial circle in 100% of cases, representing the rostral continuation of caudal communicating arteries after the origin of the middle cerebral arteries (Figure 1O). They followed rostrally and dorsally and penetrated the brain medially to the olfactory bulbs, where they branched into the medial surface of the telencephalic hemispheres. The internal ethmoidal arteries originated from rostral cerebral arteries at the rostral end of the arterial circle (Figure 1R). They branched out into the lamina cribrosa of the ethmoid bone and crista galli and ran rostrally along the nasal septum.

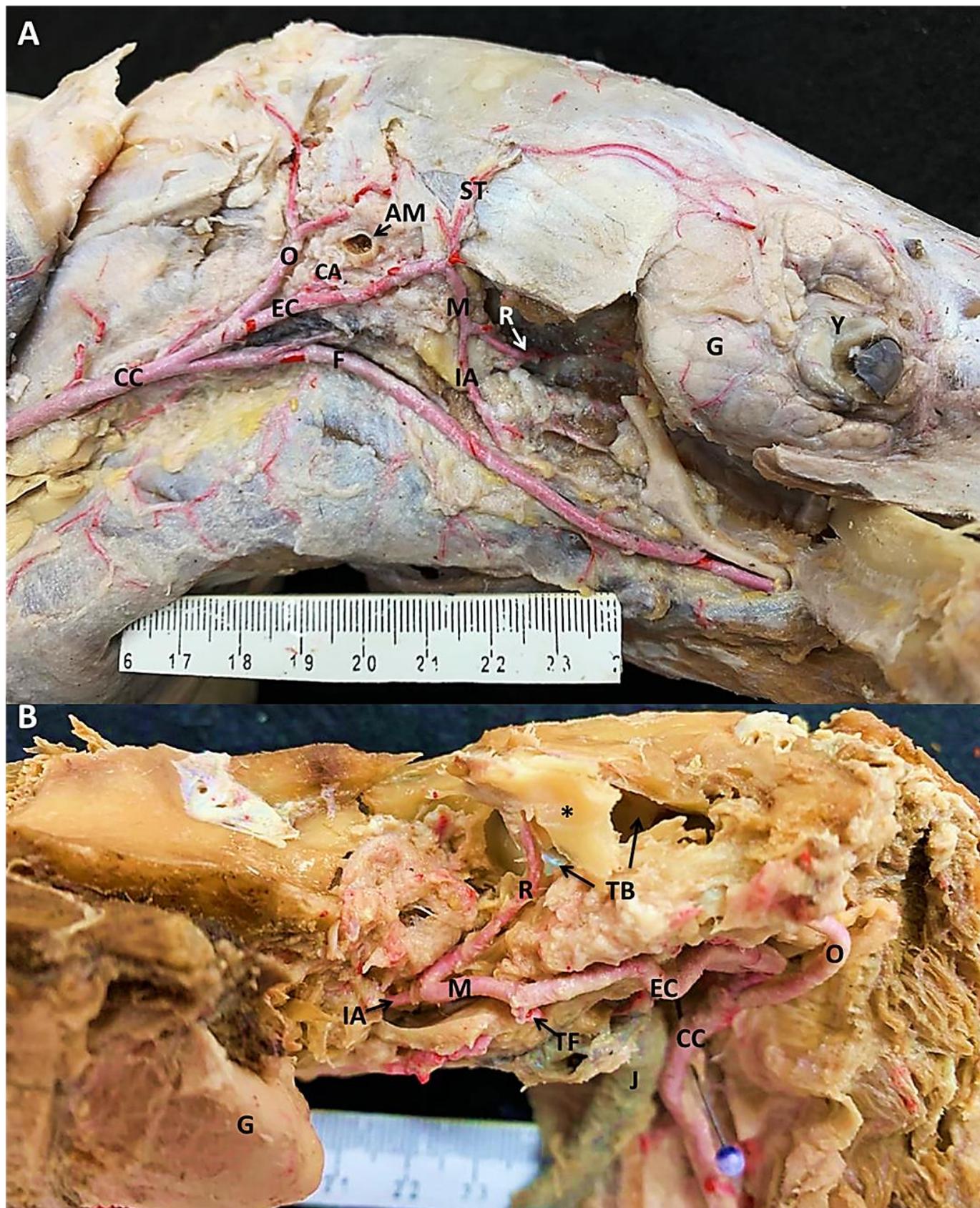


Figure 2. A) Right view of the caudal portion of the head (the zygomatic arch and part of the mandibular bone were removed) and B) Dorsal view of the left half of the skull base of an adult *M. tridactyla*. MA - external acoustic meatus; Y – eyeball; G - lacrimal gland; O - occipital artery; CA - caudal auricular artery, external carotid artery; ST - superficial temporal artery; M - maxillary artery; IA - inferior alveolar artery; TF - transverse facial artery; J - external jugular vein; R - branch to the tympanic bulla; TB – open tympanic bulla and the inner surface of its lateral wall.

The rostral cerebral arteries emitted several branches to olfactory tubercles (Figure 1P), olfactory peduncles, and two large vessels that followed the ventrolateral surface of olfactory bulbs called olfactory bulb arteries (Figure 1Q).

The middle cerebral artery was the thickest branch of the arterial circle, originating mid-rostrally at the optic chiasm level (Figure 1N). It followed laterally between the piriform lobe and the olfactory tubercle and distributed its branches on the dorsolateral surface of the telencephalon.

The caudal cerebral arteries originated from caudal communicating arteries and ran caudally between the cerebral peduncles and piriform lobes. In 50% of cases, they had a double origin in both antimeres, but just after originating, they anastomosed to follow the transverse brain fissure towards the occipital lobe of the telencephalon (Figure 1L).

4. Discussion

The brain irrigation of *M. tridactyla* corresponds to a type III in the De Vriese classification (1905), a less common pattern but also described in *Hydrochoerus hydrochaeris* (Reckziegel et al. 2001; Steele et al., 2006), *Hystrix cristata* (Aydin 2005), *Chinchilla lanigera* (Araújo and Campos 2005), and *Myocastor coypus* (Azambuja 2018), in which brain blood supply comes exclusively from the vertebrobasilar system. This pattern differs from that in cattle (Melo and Prada 1998), type I, in which irrigation is exclusive via the internal carotid artery. It also differs from *Didelphis sp.* (Lindemann et al. 2000), swine (Ferreira and Prada 2005), cats (Lima et al. 2006), and *N. nasua* (Barreiro et al. 2012), type II, in which the carotid and vertebrobasilar systems irrigate the brain, with an equivalent contribution of the two systems or one prevailing over the other.

Type II is also the pattern described in *Tamandua tetradactyla* (Lima et al. 2013), but the authors did not report the behavior of the internal carotid artery in this species. In domestic animals, this vessel is a branch of the common carotid, usually resulting from its final bifurcation into the internal and external carotid arteries (Schaller, 1999), which was not observed in *M. tridactyla* (Fig. 2). In some species such as felines, swine, cattle (Schaller, 1999), and *Hydrochoerus hydrochaeris* (Steele et al. 2006), the extracranial course of the internal carotid artery partially or completely atrophies, becoming merely a connective strand throughout the extrauterine life. Therefore, further studies are required to investigate the cephalic vasculature of immature *M. tridactyla* and other xenarthrans. The present study identified a maxillary artery branch that followed through the lateral wall of the tympanic bulla (Fig. 2, R), a similar course to that described in the literature for the internal carotid artery of some species (Wible 1986). However, our arterial perfusions did not show a connection with brain irrigation.

In *M. tridactyla*, the basilar artery was formed by anastomosis between the ventral spinal artery and vertebral arteries. These three vessels had equivalent gauges because the ventral spinal artery was quite developed in this species. The participation of the ventral spinal artery is also reported in goats (Brudnicki 2000), but the most common pattern of basilar artery formation is a convergence of the right and left vertebral arteries, as described in squirrels (Aydin, 2005, 2008), cats (Lima et al. 2006), *N. nasua* (Barreiro et al., 2012), *T. tetradactyla* (Lima et al. 2013), and *M. coypus* (Azambuja et al. 2018). Another anatomical profile is reported in horses, whose basilar artery does not result from the convergence of vertebral arteries but of the right and left occipital arteries (Campos et al. 2003). In zebu cattle (Melo and Prada 1998) and buffaloes (Faria and Prada 2001), the basilar artery results from the convergence of the caudal branches of the internal carotid artery.

All specimens (100%) in the present study showed two arterial circles along the basilar artery. These duplications, also called island anastomoses, are reported in buffaloes (Faria and Prada 2001), *C. apella* (Ferreira and Prada 2009), and equines (Campos et al. 2003). This characteristic may suggest a vestigial disposition of primitive evolutionary stages (Campos et al. 2003) because the basilar artery is primarily double, becoming single as it evolved (De Vriese 1905).

The caudal cerebellar artery was a single vessel in both antimeres, as reported for chinchilla (Araújo and Campos 2005), *T. tetradactyla* (Lima et al. 2013), and *Myocastor coypus* (Azambuja et al. 2018) but the authors mention that this vessel is the first collateral branch of the basilar artery. In the present study, bulbar branches preceded the origin of caudal cerebellar arteries.

The distribution of the middle cerebellar artery of *M. tridactyla* was similar to that of *T. tetradactyla* (Lima et al. 2013). It emerged from the rostral island of the basilar artery, but this vessel may be a collateral branch of the caudal cerebellar artery, as described in *Myocastor coypus* (Azambuja et al. 2018).

The rostral cerebellar artery was the thickest among cerebellar branches, derived from caudal communicating arteries, crossed the cerebral peduncles laterally, and distributed on the lateral surface of the cerebellum. It can be multiple in domestic animals (Shaller 1999; Campos et al. 2003) and *T. tetradactyla* (Lima et al. 2013), but it was a single vessel in *M. tridactyla*.

Caudal cerebral arteries originated from caudal communicating arteries, as observed in *T. tetradactyla* (Lima et al. 2013). Although they are double in these two Xenarthra species, in the *M. tridactyla* of the present study, the two arteries of each antimere fused and followed the transverse brain fissure closely after their origins. Conversely, they are single in most horses (Moraes et al. 2014) and *Myocastor coypus* (Azambuja et al. 2018).

In *Tamandua tetradactyla* (Lima et al. 2013) and domestic animals (Shaller 1999), rostral cerebral arteries originate from the internal carotid artery. In *M. tridactyla*, however, the rostral cerebral artery was the continuation of caudal communicating arteries closely after the origin of the middle cerebral arteries, as in *Hydrochoerus hydrochaeris* (Reckziegel et al. 2001) and *Myocastor coypus* (Azambuja et al. 2018), which also are type III vascularization by the De Vriese classification (1905).

Regardless of the arrangement in which internal carotid arteries enter the arterial circle formation, their rostral vessel calibers (rostral cerebral arteries) usually increase, as seen in the arterial circle images of *Cebus apella* (Ferreira and Prada 2009), *Nasua nasua* (Barreiro et al. 2012), and *Oryctolagus cuniculus* (Souza and Campos 2013; Portugal et al. 2014). In *M. tridactyla*, however, the caliber decreased rostrally (Fig. 1), which is also observed in the encephala images of *Hydrochoerus hydrochaeris* (Reckziegel et al. 2001), *Hystrix cristata* (Aydin 2005), *Myocastor coypus* (Azambuja et al. 2018), and *Chinchilla lanigera* (Araújo and Campos 2005), whose circles do not receive internal carotid arteries. This feature helps reinforce our thesis that vessel blood flow (sphenoidal arteries, Fig. 1 M) is efferent and not afferent.

The rhinencephalon of *M. tridactyla* is quite developed; hence, it received several branches from rostral cerebral arteries, especially the region of olfactory tubercles and olfactory peduncles. Furthermore, two large vessels followed the ventrolateral surface of olfactory bulbs and were called olfactory bulb arteries. The literature does not report these vessels.

The cerebral arterial circle was always caudally closed by the basilar artery bifurcation into caudal communicating arteries, while rostrally, it was closed by the rostral communicating artery, such as in *T. tetradactyla* (Lima et al. 2013) and about half the cases of cats (Lima et al., 2006), *M. coypus* (Azambuja et al. 2018), and rabbits (Portugal et al. 2014).

The arterial circle of the brain in *M. tridactyla* surrounded the hypophysis and the optic chiasm and consisted of caudal communicating arteries, rostral cerebral arteries, and the rostral communicating artery, as reported in domestic animals (Shaller 1999). Also, the origin of rostral communicating arteries, usually immediately rostral to the optic chiasm (Schaller 1999), occurred at the olfactory peduncle level.

Considering the elongated shape of the *M. tridactyla* encephalon, the arterial circle also assumes this pattern, with length prevailing over width and producing a fusiform aspect. This pattern differs from the hexagonal profile described in *T. tetradactyla* (Lima et al. 2013) and *M. coypus* (Azambuja et al. 2018) and from the ellipsoid shape observed in cats (Lima et al. 2006).

5. Conclusions

The blood supply of the *M. tridactyla* encephalon comes exclusively from the vertebrobasilar system, with significant participation of the ventral spinal artery. The arterial circle of the brain consists of caudal communicating arteries, rostral cerebral arteries, and the rostral communicating artery and is caudally closed by caudal communicating arteries and rostrally by the rostral communicating artery. The basilar artery presents island anastomoses, from which several collateral branches depart.

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analysis and interpretation of data, drafting the article, and critical review of important intellectual content; MOREIRA, P.C.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; QUALHATO, G.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; FIGUEIREDO, A.C.R.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; GUIMARÃES, N.N.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content; CARDOSO, J.R.: conception and design, acquisition of data, analysis and interpretation of data, drafting the article, and critical review of important intellectual content. All authors have read and approved the final version of the manuscript.

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