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Arterial vascularization of the base of the brain of *Bradypus variegatus* (Schinz, 1825)

Vascularização arterial da base do encéfalo de *Bradypus variegatus* (Schinz, 1825)

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ABSTRACT: The blood supply to the brain has unique and highly relevant characteristics, which are associated with the sensitivity, specialty and importance of the nervous tissue. Among these characteristics, the presence of an arterial circuit located at the base of the brain stands out. This circuit has modifications in relation to the different groups of vertebrates. According to the morphological model, it can be classified into three types (type I, type II, and type III) and according to the phylogenetic model, it can be classified into three stages (initial, intermediate, and final). When analyzing a sample group of 11 adult animals of the species *Bradypus variegatus*, it was found that the irrigation of the brain of this mammal is supplied by the carotid system, rostrally, and vertebrobasilar system, caudally. It is classified as type II, according to the morphological classification, and intermediate, in relation to the phylogenetic development model.

Keywords: blood supply; sloth; cerebral vasculature; xenarthra.

RESUMO: O suprimento sanguíneo para o encéfalo possui características singulares e de grande relevância, que são associadas a sensibilidade, especialidade e importância que o tecido nervoso possui. Dentre essas características se destaca a presença de um circuito arterial localizado na base do encéfalo. Esse circuito possui modificações em relação aos diferentes grupos de vertebrados. Segundo o modelo morfológico ele pode ser classificado em três tipos (tipo I, tipo II e tipo III) e segundo o modelo filogenético pode ser classificado em três estágios (inicial, intermediário e final). Ao analisar um grupo amostral de 11 animais adultos da espécie *Bradypus variegatus*, verificou-se que a irrigação do encéfalo deste mamífero é suprida pelos sistemas carotídico, rostralmente, e vertebrobasilar, caudalmente. Classificado como tipo II, segundo a classificação morfológica e intermediário, em relação ao modelo de desenvolvimento filogenético.

Palavras-chave: irrigação sanguínea; bicho-preguiça; vascularização cerebral; xenartros.

INTRODUCTION

Brain irrigation has a specificity that occurs along with the noble and specialized structures found in the brain. In its functional activity, the brain lacks a continuous and intense blood flow due to the high consumption of glucose and oxygen (Zhu; Lu; Chen, 2018). The interruption of this blood flow can lead to irreversible injuries, since there is no cellular regeneration in the nervous tissue. For prophylactic measures, diagnosis, and treatment, it is necessary to know the anatomy and functionality of this vascularization, compared to arteries of the same caliber in other regions of the body, and the presence of an arterial circuit at the base of the brain (Machado; Haertel, 2013).

Comparatively between species, this arterial circuit consists of a circuit located at the base of the brain, where the behavior of these arteries demonstrates a basic model to which modifications related to different groups of animals are added (Machado, 1993; Prada, 2014), and where morpho-functional studies of the nervous system, related to the blood supply to the brain, have found relevant characteristics (Lima *et al*., 2013).

In his study on the cerebral arterial circuit, De Vriese (1905) pointed out the phylogenetic importance of this circuit, as well as its parallelism with the development of the nervous system.

Related to the phylogeny of cerebral arteries, De Vriese (1905) classified the brain irrigation of vertebrates into three types: Type I, brain irrigation is carried out almost entirely by the internal carotid arteries. Type II: the brain is partially irrigated by the internal carotid and vertebral arteries, with equal distribution between the two systems or the predominance of one of them; and type III, in which the brain is irrigated almost exclusively through the vertebrobasilar system (Prada, 2014; Gomes *et al*., 2019).

It is also worth noting that for different groups of mammals, brain irrigation has different aspects, arrangements, and implications that need to be studied (Lima *et al.,* 2005). The morpho-functional understanding of the brain arterial circuit of *B. variegatus* (Schinz (1825)) is necessary not only

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because of the physiological, clinical, and phylogenetic importance of this system, but also because these animals are constant victims of falls (Xavier *et al.,* 2015), and electric shocks, among other risk factors, which often lead to the animal's death (Xavier *et al.,* 2010). This demonstrates the need to understand the *B. variegatus* in greater depth in order to contribute to the knowledge of its vascularization, which is of fundamental biological and clinical importance to the animal (Campos, 2014). Thus, this study was carried out with the objective of describing the anatomy of the arterial circuit of the brain of the sloth (*B. variegatus).*

MATERIAL AND METHODS

The study was submitted and approved by the Animal Use Ethics Committee - CEUA of the Federal Rural University of Pernambuco, with license number (129/2019).

This research was carried out in the Anatomy Area of the Department of Animal Morphology and Physiology of the Federal Rural University of Pernambuco (DMFA/ UFRPE). Eleven adult sloths of the species *B. variegatus* were used, acquired after death and provided by the Wildlife Triage Center (CETRAS-TANGARA). For naming purposes, the "International Committee on Veterinary Gross Anatomical Nomenclature (2017)" was used.

Ten animals received an injection of latex stained with red pigment from the cannulation of the common carotid artery, for better arterial visualization. Subsequently, fixation was performed in a 10% aqueous solution of formaldehyde. After the fixation process, the animals were kept in a tank of 30% saline solution, for their preservation. Subsequently, the skin and muscles of the head were folded back in these animals, to access the bones of the skull, and then a bone window was opened in the parietal bones extending to the occipital bone, with the aid of a saw and pliers. With access to the cranial cavity (endocranium), the brain was removed with part of the cervical segment of the spinal cord. Then, the pieces were kept in 20% formalin for a minimum period of 24 hours. After this process, the pieces were dissected to allow observation and recording of the behavior of the vessels, where the meninges were removed. All brains were then kept in jars with 10% formalin.

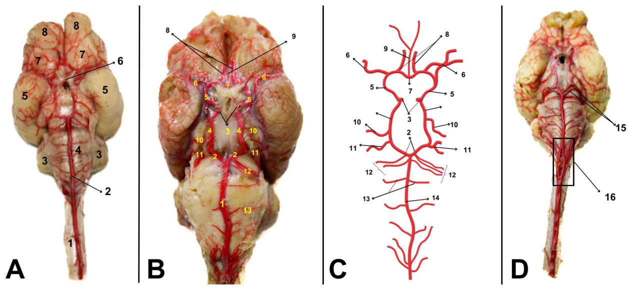
Furthermore, the vinyl acetate (vinylite) molding technique was performed on an adult male specimen. The vinyl was previously prepared, homogenized in acetone PA, and kept in a glass container without exposure to light for 48 hours. After 48 hours, red oil paint was added to the vinylite solution and the animal was prepared for the filling technique. The colored solution was injected cranially and caudally into the previously cannulated common carotid artery. Then, with the aid of a saw, pliers, scalpel, tweezers, and surgical scissors, the appendicular skeleton, ribs, skin, and muscles were removed, and kept immersed in water for 24 hours. After 24 hours, the specimen was then submerged in two liters of an aqueous solution of 33% HCl (hydrochloric acid) for five days. After this period, the piece was washed with a fine jet of water in order to remove any remaining organic material. The piece then dried at room temperature and was analyzed later.

RESULTS

It was observed that the irrigation of the base of the brain of *B. variegatus* is supplied by the carotid system, rostrally, and vertebrobasilar system, caudally, forming a closed arterial circuit, located ventrally at the base of the brain, with non-polygonal morphology.

The rostral cerebral artery originates from the internal carotid artery in both antimeres and is located laterally to the optic chiasm. It is interconnected by the rostral communicating artery, which is located mid-rostrally to the longitudinal fissure of the brain, and rostrally closes the arterial circuit. The latter gives off the interhemispheric artery, which projects rostrally to the longitudinal fissure, contributing to the irrigation of the frontal lobe of the brain, olfactory bulb and corpus callosum. Still in the rostral portion of the circuit, the internal ethmoidal artery emerged from the rostral cerebral artery and projected towards the olfactory bulb. The middle cerebral artery originated from the rostral cerebral artery in both antimeres and projected rostrally around the piriform lobe and extended to the dorsolateral area of the cerebral hemispheres (Figure 1).

Figure 1 – A, B, D - Brain of *Bradypus variegatus* (ventral view), with arteries filled with red-stained latex. **C-** Diagram of the arterial circuit of the base of the brain of *B. variegatus.* In **A-** (1) spinal cord; (2) straight basilar artery; (3) cerebellum; (4) brainstem; (5) pear-shaped lobe; (6) optic chiasm; (7) olfactory tubercle; (8) olfactory bulb. In **B, C** and **D -** (1) sinuous basilar artery; (2) terminal branch of the basilar artery; (3) internal carotid artery; (4) caudal communicating artery of the internal carotid artery; (5) rostral cerebral artery; (6) middle cerebral artery; (7) rostral communicating artery; (8) ethmoidal artery; (9) interhemispheric artery; (10) caudal cerebral artery; (11) rostral cerebellar artery; (12) middle cerebellar artery; (13) caudal cerebellar artery; (14) straight basilar artery; (15) double basilar terminal branch; (16) arterial rhombus.

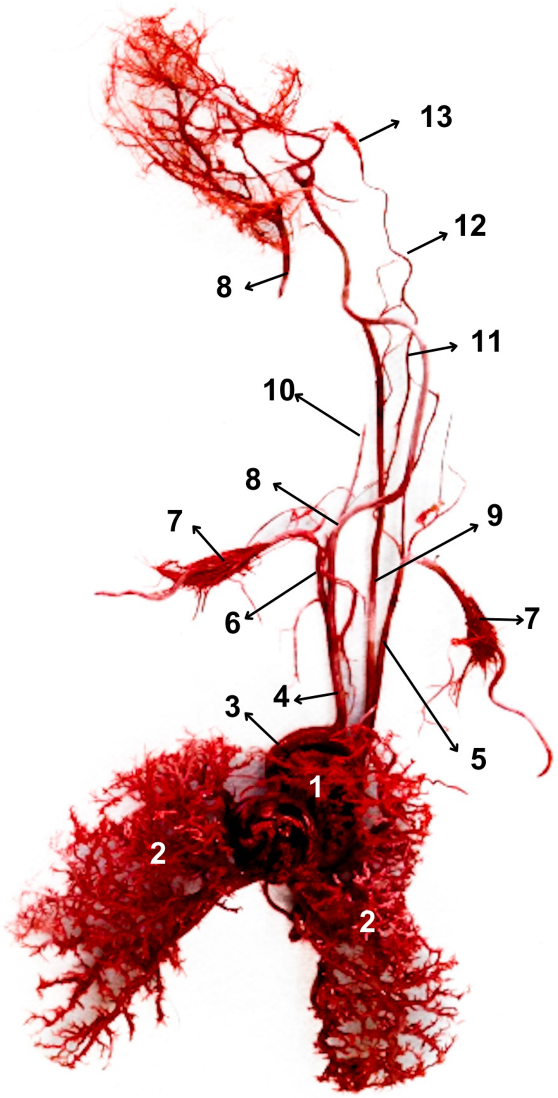


Source: Author's collection.

The caudal portion of the arterial circuit of the brain is formed by the right and left caudal communicating arteries of the internal carotid arteries, from which the caudal cerebral arteries originate. The caudal communicating arteries of the internal carotid artery continue caudally and anastomose with the terminal branches of the basilar artery, closing the circuit caudally. The caudal cerebral artery emerged from the caudal branches of the right and left internal carotid arteries, in both antimeres, projecting dorsum-laterally, reaching the occipital lobe of the cerebral hemispheres, as well as emitting branches to the caudal region of the piriform lobe (Figure 1).

The basilar artery is located medially in the brainstem, with contributions from the vertebral arteries. The right and left vertebral arteries undergo anastomosis in the ventral portion of the midline of the spinal cord, at the level of the cervical vertebrae (Figure 2). The anastomosis of the vertebral arteries continues cranially, entering the skull and forming the basilar artery, which then bifurcates to form the terminal branches of the basilar artery.

Figure 2 – Red-stained vinyl acetate cast of the arteries of the heart, lung, aortic trunk and its branches, and cranial arterial branches of *B. variegatus.* (1) Heart; (2) Pulmonary arteries ; (3) Aortic arch; (4) Right brachiocephalic trunk; (5) Left subclavian artery; (6) Right subclavian artery; (7) Admirable networks; (8) Right common carotid artery; (9) Left common carotid artery; (10) Right vertebral artery; (11) Left vertebral artery; (12) Anastomosis of vertebral arteries; (13) Basilar artery; Note: in the image, the right common carotid artery was ruptured in the corrosion process.



Source: Author's collection.

In four specimens, the terminal branches of the basilar artery were double in both antimeres. It was also observed that in seven animals, the basilar artery had a sinuous path, while in four animals the basilar artery had a straight path. In three animals the basilar artery formed an arterial diamond at its base (Figure 1).

The rostral cerebellar arteries in both antimeres arise from the caudal communicating artery of the internal carotid artery, which projects laterally to irrigate the cerebellar hemispheres rostral laterally. The middle cerebellar arteries arise from the terminal branch of the basilar artery. And the caudal cerebellar arteries arise from the basilar artery and project caudally and caudolaterally (Figure 1).

Thus, according to the morphological classification, the circuit of the base of the encephalon of the common sloth is characterized as type II alpha, since the internal carotid artery is mainly responsible for the formation of the cerebral arteries and emitting anastomosis with the terminal branches of the basilar artery. Regarding the model of phylogenetic characters, the arterial circuit of *B. variegatus* is classified as intermediate, when there is a contribution of the basilar artery to the brain blood supply.

DISCUSSION

The morphology of the arterial circuit of *B. variegatus* does not have a polygonal shape as described in humans by Willi (1664). This divergence, however, is observed in models of vascular architecture of the arterial circuit at the base of the brain in animal species as reported in pigs of the Camborough 22 lineage (Lima *et al.,* 2005), wild boar (Santos *et al.,* 2011), *Eira barbara* (Macedo *et al.,* 2014), dog (Alcântara; Prada, 1992) and anteater, where the latter presented hexagonal morphology (Lima *et al.,* 2013).

The arterial circuit supply in *B. variegatus* is carried out by the basilar and right and left internal carotid arteries, as found in most animal species and even in humans (Prada, 2014). However, these pathways do not present a variation in caliber that would imply importance, a characteristic also observed and highlighted in *Eira barbara* (Macedo *et al.,* 2014).

Regarding its morphological classification, it was possible to observe a tendency towards type II alpha described by De Vriese (1905) and phylogenetically towards model II Testut (1911). A characteristic model of several species, such as coati (Barreiro *et al.,* 2012), equine (Campos *et al.,* 2003), cat (Lima *et al.,* 2010), *Eira barbara* (Macedo *et al.,* 2014), and lesser anteater (Lima *et al.,* 2013).

The circuit was closed rostrally by the cerebral communicating artery and rostral cerebral artery, which was also seen in the lesser anteater. Caudally, the circuit was closed by the anastomosis of the terminal branches of the basilar artery. This characteristic is different from that described by Lima *et al.* (2013) for the lesser anteater, a species that belongs to the order pilosa, which is the same as the common sloth. In the lesser anteater, the circuit is closed caudally by the anastomosis of the caudal communicating artery of the internal carotid with the basilar artery (Lima *et al.,* 2013), while in the common sloth, the caudal branch of the internal carotid anastomoses with the terminal branch of the basilar artery and not directly with the basilar artery.

Such morphological divergence in the arterial circuit of two species of the same order may indicate phylogenetic characteristics related to the development of the central nervous system; however, they may be just morphological adaptations of the species (De Vriese, 1905; Prada, 2014).

The rostral conformation of the arterial circuit of the common sloth occurred through the rostral cerebral artery, ethmoidal artery and interhemispheric artery. The presence of the cerebral artery in this formation is common to different species such as horses, cattle (Getty, 1986; Prada, 2014) and the lesser anteater (Lima *et al.*, 2013). However, for the species mentioned, the irrigation of this region also counts on the presence of the rostral communicating artery projecting rostroventrally, which differs for *B. variegatus* where the rostral communicating artery connects the right and left cerebral arteries. The emergence of the rostral cerebral artery in *B. variegatus* can be correlated with the findings for the lesser anteater (Lima *et al.,* 2013) and wild boar (Santos *et al.,* 2011), emerging from the internal carotid artery.

Still in the rostral region of the circuit is the internal ethmoidal artery, which is also present in pigs (Prada, 2014), wild boars (Santos *et al.,* 2011), and the lesser anteater (Lima *et al.,* 2013), and the interhemispheric artery that was also verified for *Alouatta belzebul* (Sabec-Pereira *et al.*, 2020). In the finding of Lima *et al.* (2013), the middle cerebral artery projects laterally to the pear-shaped lobe, while in *B. variegatus,* it contours the piriform lobe rostrally, and caudally to the olfactory tubercle.

In the caudal part of the arterial circuit of the brain of *B. variegatus,* in turn, there is the caudal cerebral artery, which emerges from the caudal communicating artery of the internal carotid artery, and by the branches derived from the basilar artery (caudal terminal branches of the basilar, rostral cerebellar artery, middle cerebellar artery, and caudal cerebellar artery). This conformation is similar to that presented by the lesser anteater (Lima *et al.,* 2013), with the exception of the terminal branches of the basilar artery.

Considering the phylogenetic and ontogenetic evolution model of Testut (1911), the caudal cerebral artery of the common sloth coincides with the intermediate stage, since it is related to the internal carotid artery, more specifically to the caudal branch of the internal carotid artery. This characteristic demonstrates the greater relevance in the circuit of the internal carotid artery.

In literature, the origin of the basilar artery in *B. variegatus* was unusual, where the vertebral arteries participate, in most animals, in the formation of the basilar artery at the cranial level (Prada, 2014). However, literature also records the existence of animals in which the basilar artery has its origin in the occipital arteries, as is the case of horses (Santos, 1987; Campos *et al.,* 2003) and pigs (Ferreira, 1998; Ferreira; Prada, 1999). The contribution of the vertebral arteries to the brain arterial circuit of *B. variegatus* is different from other descriptions found in literature for different species, its contribution occurs at the level of the cervical vertebra. This differs from what was described by Lima *et al.* (2013), where the vertebral arteries penetrate the foramen magnum undergoing anastomosis to form the basilar artery.

The origin of the vertebral arteries occurred through the subclavian artery, which is relatable to different species of mammals (Getty, 1986). As described by Albuquerque *et al.* (2018), in the specimen studied, the aortic trunk gave rise to a right brachycephalic trunk, the left common carotid artery and the left subclavian artery. The right common carotid artery and the right subclavian artery depart from the brachycephalic trunk. This pattern was observed by Albuquerque *et al.* (2018) in 75% of females and 66.7% of males, coinciding with the pattern observed in the specimens analyzed.

The presence of terminal branches of the basilar artery observed in the common sloth may correlate with that of Thoroughbred horses (Prada, 2014; Santos, 1987). As in the lesser anteater (Lima *et al.,* 2013), the rostral cerebellar artery originated from the communicating caudal artery of the internal carotid artery. However, it differs in relation to the origin of the caudal cerebellar arteries, which in the common sloth originate from the basilar artery.

CONCLUSIONS

Bradypus variegatus presents a closed cerebral arterial circuit, with rostral supply from the carotid system and caudal supply from the vertebrobasilar system. The vascular anatomy observed had relevant variations, such as anastomosis of the vertebral arteries occurring at the level of the cervical vertebrae, and duplication of the terminal branches of the basilar artery in some specimens. These findings contribute to the knowledge of the comparative anatomy of the central nervous system in Xenarthra and reinforce the importance of vascular characterization in different species, with implications for evolutionary, biomedical, and conservation studies.

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