Original article

Anatomical arrangement and distribution of the cerebral arterial circle in rats

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Abstract

The cerebral arterial circle is a polygonal shape-like arterial anastomosis placed in the brain base, where it rounds the optic quiasm and the tuber cinereum, and also related to the interpeduncular fossa and the anterior perfurated substance. It is formed by the proximal parts of the anterior, middle and posterior cerebral arteries, and the right and left posterior communicating arteries. In order to describe the cerebral arterial circle disposition we investigated the brains of twenty rats. For each animal, the heart left ventricle was probed and acetone, distilled water at 37 °C and a solution of Neoprene Latex "450" stained with a specific red pigment were injected in sequence into it. To fix the brain in a better way, we isolated the head and made an aperture at the dorsal wall of the cranium and the whole specimen was fixed in a 15% formaldehyde solution. We took off the brain from the skull with the aid of a cold light source monocular magnifier. To take the photographic data we used a semi-professional camera. The results showed that the cerebral arterial circle in rats is formed by branches of both internal carotid arteries and of the basilar artery, and is closed rostrally by the rostral communicating artery, and caudally by the right and left terminal branches of the basilar artery. We concluded from our data that the cerebral arterial circle in rats is compound by branches of both internal carotid arteries and basilar artery, and that it is rostrally and caudally closed.

Keywords: anatomical disposition, cerebral arterial circle, brain, rat.

1 Introduction

The cranial base is site of several pathological processes that require surgical or invasive neuroradiological interventions in order to prevent morbidity/mortality. The surgical approach to this region demands a perfect anatomical knowledge, not only of the normal features but mainly of the variations of the many structures found there. So, because of the complex anatomy of the cranial base, it is not unusual that many authors had dedicated a special attention to the morphology of the cerebral irrigation, in particular the cerebral arterial circle (circle of Willis), concerning various surgical different contexts, for example, cranial base tumors (NGUYEN and DELASHAW, 1995; HARSH, JOSEPH, SWEARINGEN et al., 1996, BOYLE, SHAH and SHAH, 1998) and vascular lesions (STEHBENS, 1990, SHIN and PERSING, 1995, CHALOUPKA and PUTMAN, 1995, VASCONCELOS, XAVIER, ALMEIDA-PINTO et al., 2001).

In Brazil (2000), among the cerebral vascular diseases that affects individuals from 20 to 59 years old, acute encephalic vascular accident (EVA) corresponded to a little bit more than 80% of the hospital internment maintained by the Health System. But beyond this high incidence, one also must consider the severe social and medical consequences that arise from EVA cases, such as physical sequels, communication disorders, emotional imbalances, functional disabilities and so on (FALCÃO, CARVALHO, BARRETO et al., 2003).

Basically, the cerebral blood circulation depends on two nourishing systems: (1) the carotid system, the main responsible for the irrigation of the anterior three-quarters of the cerebral hemispheres by the anterior and middle cerebral arteries and the anterior choroidal artery, and (2) the vertebrobasilar system, that provides the brainstem, the cerebellum and the posterior quarter of the cerebral hemispheres by the posterior cerebral artery. The clinical presentation and follow-up of patients with injuries in the areas provided by these two systems differ radically and the establishment of an early diagnosis is very important.

The pattern of origin and distribution of the cerebellar arteries and their anastomosis have been studied in mammals and submammals, as marsupials, xenarthres (*armadillo*), carnivores, ungulates, dogs and primates, as well as the evolution of the knowledge about the morphology of the anterior cerebral artery in human beings. It was observed the presence of the anterior inferior cerebellar artery and superior cerebellar arteries in rodents (SILVA and FERREIRA, 2002).

Pinto e Silva et al. (2010) reported that the brain of *Didelphis albiventris* (white-eared opossum) presents a rich vascular network. Each principal artery shows several branches which courses to distinct areas. The cerebral artery circle is formed by vascular branches arising from the internal carotid arteries and basilar artery. The rostral cerebral artery makes an anastomosis with the contrallateral one by the rostral communicating artery. The caudal communicating artery spreads out to the cerebellum, where it emits the caudal cerebral and the rostral cerebellar arteries.

For Araújo (2004), chinchilla's cerebral arterial circle (*Chinchila lanigera*) presented caudally closed in 100% of the preparations by the bifurcation of the basilar artery in its two terminal branches, but it showed to be rostrally opened in 70% of the samples and closed only in 30%. In seven cases of rostral closure, it was made by the anastomosis between the collateral branches of the rostral cerebral arteries of both sides, and in two cases the closure was due to an anastomosis between the median rostral inter-hemisphere artery of one side and a fine branch arising from the olfactory bulb's medial artery of the other side. Chinchilla's cerebral arterial circle is provided almost exclusively by the vertebrobasilar system but it is also important to stand out the presence of an anatomical variation which consists of full-patency and development of the left internal carotid artery, that in 3.3% it acts as a supplementary source of blood supply whereas in 3.3% it forms the whole cerebral arterial circle. The chinchilla's brain blood supply is classified as type III of De Vriese classification (1905).

Ferreira and Prada (2005) studied the cranial base's cerebral arterial circle in hogs and stated that it is formed by the division of both internal carotid arteries into their rostral and caudal terminal branches. Rostrally, it presents itself as a small medial-concave arch on both sides; caudally, it resembles a polygon – the inferior half of a hexagon (53.3%) or a heart-shape figure (46.7%). Rostrally, the cerebral arterial circle is closed by a constant rostral communicating artery present in all preparations and, caudally, by the right and left terminal branches of the basilar artery. In 10% of the cases, besides the terminal branches mentioned above, the cerebral arterial circle showed two tiny anastomosis in the site of the arterial bifurcation.

In capuchin monkey (*Cebbus apela*), the caudal cerebral artery is a terminal branch of the basilar artery and represents the rostral branch of the vertebrobasilar system. Although one has observed caudal cerebral arteries without anatomical variations in their origins, they bifurcated from the basilar artery in 25 brains. The caudal cerebral arteries can be divided in four parts called precommunicating, postcommunicating, temporal and cortical; the temporal part emits branches to the temporal, occipital and parietal regions; the middle and posterior temporal regions receive the longest and thickest branches of the temporal branch; in their cortical route the caudal cerebral arteries supply the anterior temporal region with tiny branches; the occipital region and the part of the parietal region close to the former are nourished by arterial branches derived from the main temporal arterial trunk; the caudal cerebral arteries and their branches are anatomically stable since their arrangements did not show anomalies or great variations that could interfere in the functions they were meant for (SILVA and FERREIRA, 2002).

Mendoza, Tirado, Figueroa et al. (2009) described the cerebral carotid-arterial irrigation of the domestic chicken. In the intercarotid anastomosis (IA), the formation of the basilar artery by the posterior cerebral artery with the total absence of the vertebral arteries, is a remarkable cerebral arterial anatomical feature in this specie. Apparently, the IA is an exclusive anatomical trait of birds certainly related to evolutional mechanisms that affect the physiological events concerning cerebral hemodynamics, homeostasis, and physiological and adaptive mechanisms for flight. In relation to the similarities shared by birds and mammals it must be emphasized that birds do not have a cerebral arterial system as complex as the mammals (Willis circle) but the IA is a structure placed in the cranial base where the internal carotid arteries join together before they nourish the cerebral parenchyma. Due to this type of morphology, the blood flow diffuses bilaterally to both cerebral hemispheres.

For Nazer (2009), the carotid arteries of ostriches (*Struthio camelus*) present rostral and caudal terminal branches. The rostral one shows collateral branches, the middle and caudal cerebral arteries, and a terminal branch, the cerebroethmoidal artery. These arteries spread out and irrigate the whole cerebral hemisphere, the dorsal surface of the optic lobe and the rostral part of the vermis of cerebellum. The cerebral carotid arteries present an intercarotid anastomosis (IA) within the sella turcica, probably with the same function as the cerebral arterial circle which is always rostrally opened but caudally opened in only 80% of the brains and closed in the other 20%. The blood irrigation of the ostrich's brain, exclusively provided by the carotid system, is classified as type I of De Vriese classification (1905).

Prada, Campos and Santos (2003) studied the cerebral circulation in equines and demonstrated that the basilar artery is formed by the convergence of the right and left occipital arteries (and not of the vertebral arteries) which in correspondence to the ventral surface of the bordering region between bulb and spinal cord describe rostrally a lateral or medial-concave arch and, doing so, always maintaining a close relationship to the ventral spinal artery in varied arrangements; the pattern exhibited by the behavior of the occipitobasilar system forming arteries, in the studied animals, is classified between the middle and final stages.

Casal, Arantes, Casimiro et al. (2005) reported that the circle of Willis in dogs (*Canis familiaris*) is formed caudal and laterally by the two caudal communicating arteries that extend themselves from the basilar trunk to the correspondent internal carotid artery. Rostral and laterally, the circle showed to be always formed by the rostral cerebral arteries which, arising at the level of the internal carotid artery at the same side, converged and made anastomosis at their most cranial position thus originating the median artery of the corpus callosum.

In humans and animals, brain's blood supply is very important and vital. It maintains alive one of the principal organs in a living being. Any anomaly, blood vessels rupture or blood flow interruption can generate unrecovered consequences to the organism, such as encephalic vascular accident (EVA), ischemia, aneurism subarachnoid hemorrhage, etc. Because of these, this study proposes to describe the anatomical arrangement and distribution of the cerebral arterial circle in rats, by means of latex injection, aiming to help future studies on preventive and/or treatment methods, especially those concerning anomalies that cause neurological disturbances.

2 Materials and Methods

The research project was appreciated and approved by the Research Ethics Committee and the Animal Experimentation Ethics Committee of the Federal University of Alfenas - UNIFAL-MG (register 224/2009). The experiment was accomplished using twenty rats. For each animal, the heart left ventricle was probed and acetone P.A., distilled water at 37°C and a solution of Neoprene Latex "450" stained with a specific red pigment were injected in sequence into it. To fix the brain in a better way, one isolated the head and neck and made an aperture at the dorsal wall of the cranium and the whole specimen was fixed in a 15% formaldehyde solution for at least three days (FERREIRA and PRADA, 2005). After the minimum-time for fixation, one took off the brain from the skull with the aid of a cold light source monocular magnifier. To take the photographic data we used a semi-professional Nikon Coolpix P100 camera. The declination of anatomical elements followed that of the International Committee on Veterinary Gross Anatomical Nomenclature (INTERNATIONAL..., 1994).

3 Results

The data obtained from this systematic study of the anatomical arrangement and distribution of the cerebral arterial circle in rats (*Rattus novergicus*) are shown in Figures 1 to 8 and described as follows:

3.1 Basilar artery

This artery arose from the anastomosis of the terminal branches of the right and left vertebral arteries at the foramen magnum. It was a straight and medium-sized blood vessel that extended rostrally in the hindbrain's ventral median line until it reached the rostral groove of the pons where it divided on both sides into a rostral cerebellar branch and two terminal branches (Figure 1). These blood vessels diverged, at the level of the rostral groove of the pons, deep into the interpeduncular fossa, their branches projecting themselves in divergence and giving birth to the caudal cerebral artery.

On both sides, the basilar artery sent a sequence of collateral branches that nourish the bulb, pons and part of the cerebellum (Figure 2). Small-sized branches for the bulb and the pons were many: a) rostral cerebellar artery (right and left), a medium-sized blood vessel derived from the terminal branch of the basilar artery. It threw dorsolaterally, surrounded the cerebral peduncle rostrally to the rostral groove of the pons, and subdivided in the caudal colliculus and rostral, middle and caudal cerebellar lobules; b) caudal cerebellar artery (right and left), a single but often duplicated large-sized blood vessel that arose from the caudal terminal branch of the internal carotid artery (right and left). It contoured the pyriform lobe posteriorly and the cerebral peduncle anteriorly to reach out the tentorial and medial surfaces of the cerebral hemisphere, going as far as the caudal third of the latter one (Figure 3).

3.2 Internal carotid artery (right and left)

After its origin from the common carotid artery, this blood vessel coursed in brain's base laterally to the hypothalamus cooperating with the brain blood supply. At the site of its arrival in the brain's base, it divided into two terminal branches, a rostral and a caudal one, corresponding to the confluence point with the basilar artery's terminal branch (Figure 4). In the dissected specimens, the internal carotid artery passed through the foramen lacerum's carotid notch or the carotid canal to project itself rostrally until the level of the hypophysis where it eventually branched in the brain.

3.3 Rostral branch of the internal carotid artery (right and left)

This blood vessel gave origin to (a) the middle cerebral artery (right and left), a rostral terminal branch of the internal carotid artery, which coursed laterally at the level of the optic quiasm and deep into the lateral fossa (Figure 5). There, it travelled rostrally to the pyriform lobe and sent several collateral branches to these two structures and its main trunk divided on the dorsolateral surface of the cerebral hemisphere (Figure 6); (b) the rostral cerebral artery (right and left), a terminal branch of the internal carotid artery

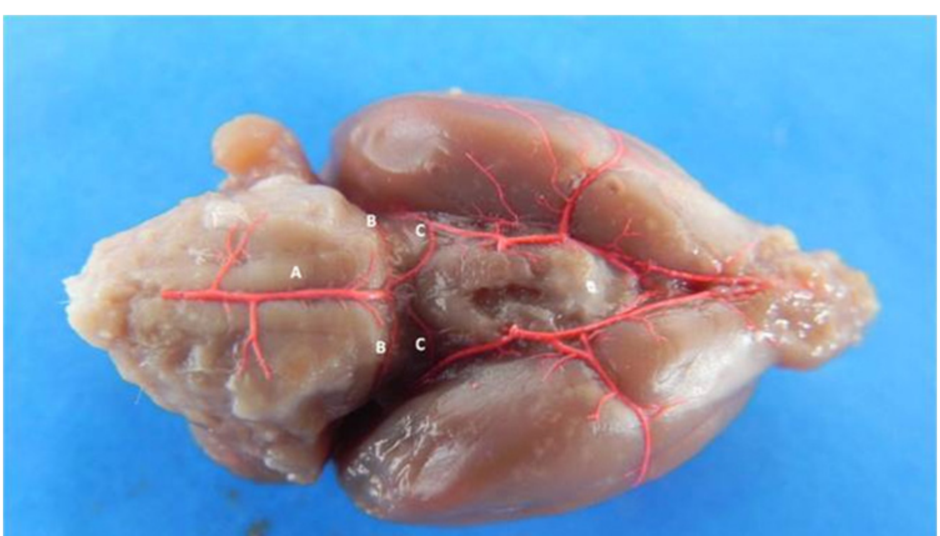

Figure 1. Macroscopic photography of a rat's brain base showing the basilar artery (A) extending rostrally in the ventral median line and dividing on both sides into the rostral cerebellar branch (B) and the two terminal branches (C).

(right and left), which arose rostromedially by the origin of the middle cerebral artery. Its first presenting collateral branch housed itself in the ventral longitudinal fissure and, from there, continued rostrally to emit the internal ophthalmic artery (Figure 7).

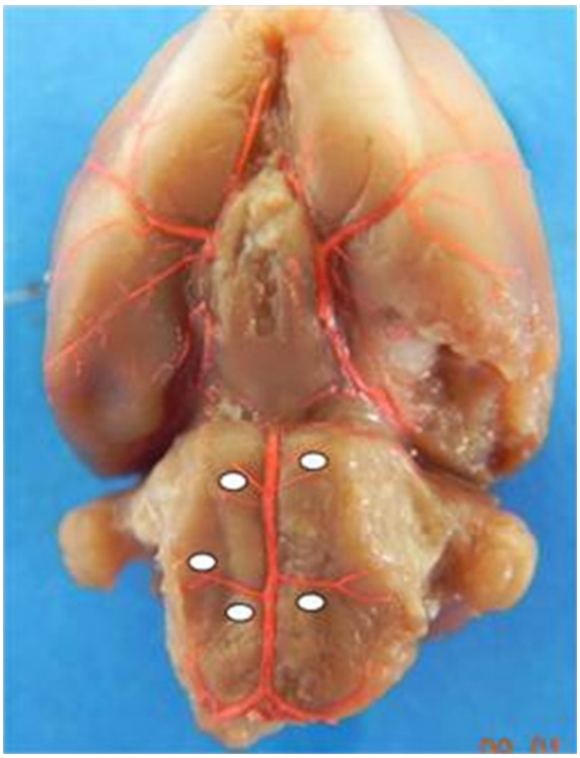

Figure 2. Macroscopic photography of a rat's brain base showing on both sides the basilar artery emitting a sequence of collateral branches that nourish the bulb, pons and part of the cerebellum (white dots).

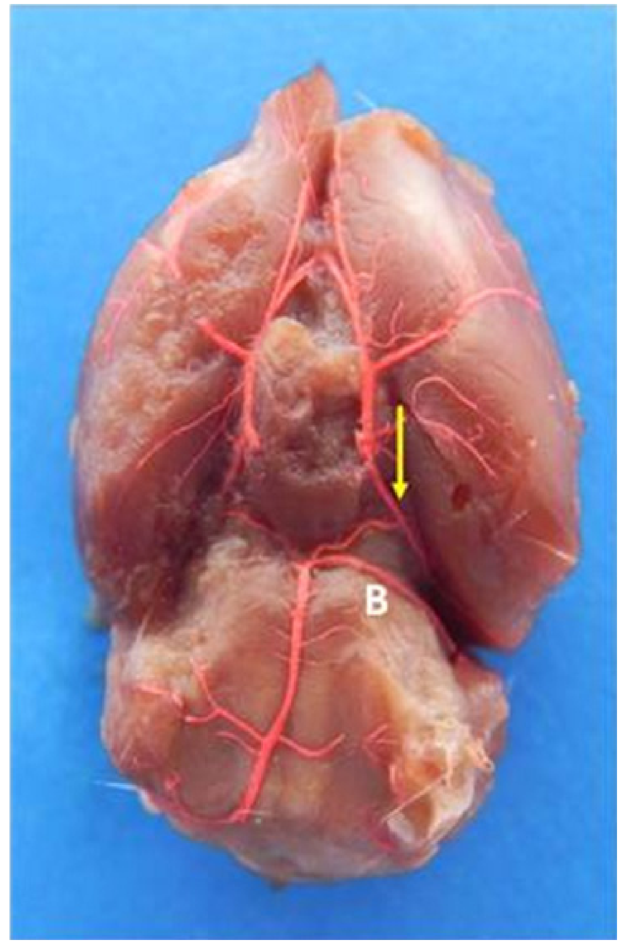

Figure 3. Macroscopic photography of a rat's brain base showing collateral branches from the basilar artery's terminal branches: rostral cerebellar artery (B) and caudal cerebral artery (yellow arrow).

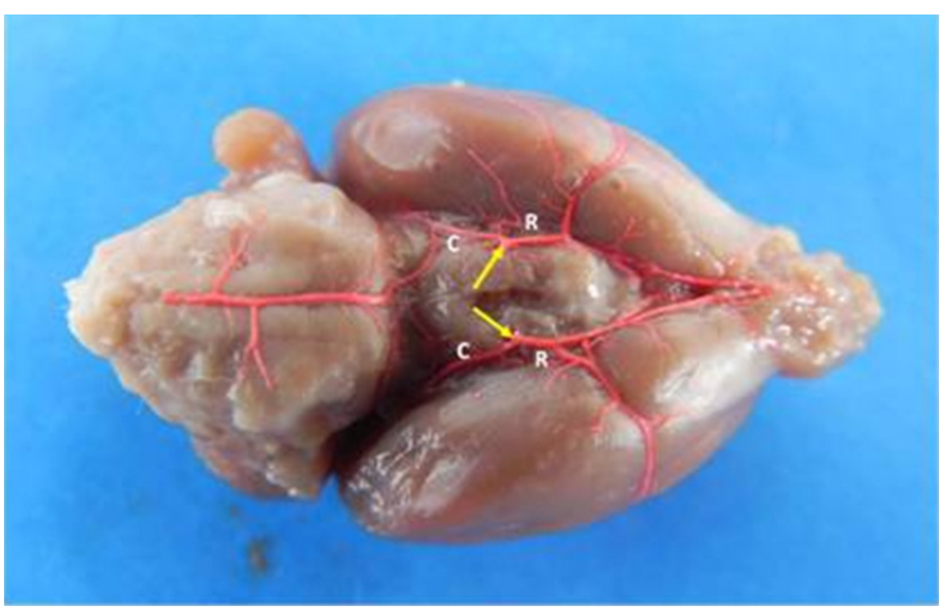

Figure 4. Macroscopic photography of a rat's brain base showing the site of the arrival of the internal carotid artery (yellow arrow) and its division into two terminal branches, a rostral (R) and a caudal (C) one.

Figure 5. Macroscopic photography of a rat's brain base showing the middle cerebral artery (white arrows).

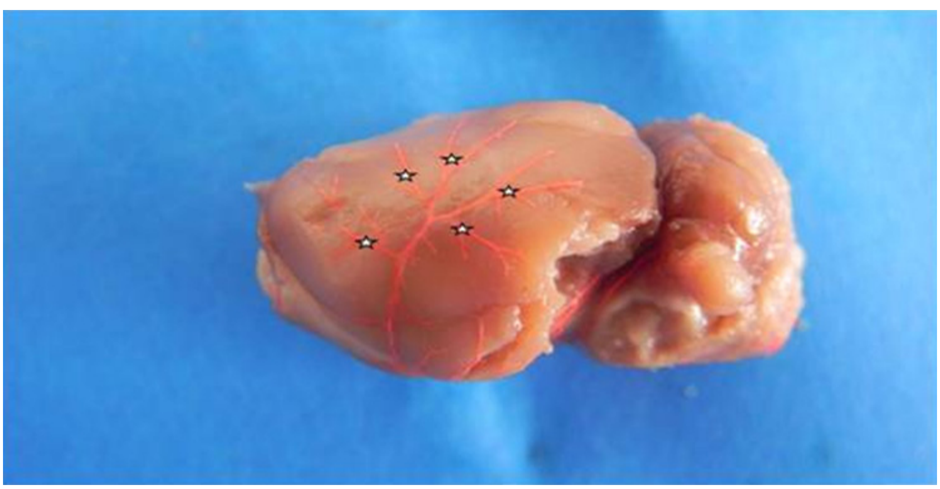

Figure 6. Macroscopic photography of a rat's brain base showing many collateral branches arising from the middle cerebral artery (white stars) and its main trunk dividing on the dorsolateral surface of the cerebral hemisphere.

3.4 Collateral branch of the rostral cerebral artery (right and left)

From this branch spread out the lateral bulb artery (right and left), a small-sized blood vessel that took origin from the rostral cerebral artery (right and left), projected itself rostrolaterally and subdivided to nourish the olfactory bulb (Figure 8).

3.5 Terminal branch of the rostral cerebral artery (right and left) - rostral communicating branch

This branch was placed rostrally to the optic quiasm and was found closing anteriorly the cerebral arterial circle. The right and left internal ethmoidal arteries started from it (Figure 8). The ethmoidal artery (right and left)**:** its origin was considered to be at the site of the anastomosis with the rostral communicating branch. This blood vessel was emitted in a rostral sequence close to the level of the origin of the single rostral median hemispheric artery (Figure 9). The internal ethmoidal artery passed through the cribriform plate of the ethmoid bone and spread out on its labyrinthi in the nasal cavity. Thus in all dissected animals, the cerebral arterial circle was closed rostrally by the stable presence of the rostral communicating artery, and caudally by the presence of the right and left terminal branches of the basilar artery.

4 Discussion

In this item one will compare the cerebral arterial circle of the rat with those of the ostrich (*Struthio camelus*), dog (*Canis familiaris*), horses (*Equus ferus*), hen (*Gallus gallus*), white-eared opossum (*Didelphis albiventris*), capuchin monkey (*Cebus apella*), and hog (*Sus scrofa domesticus*).

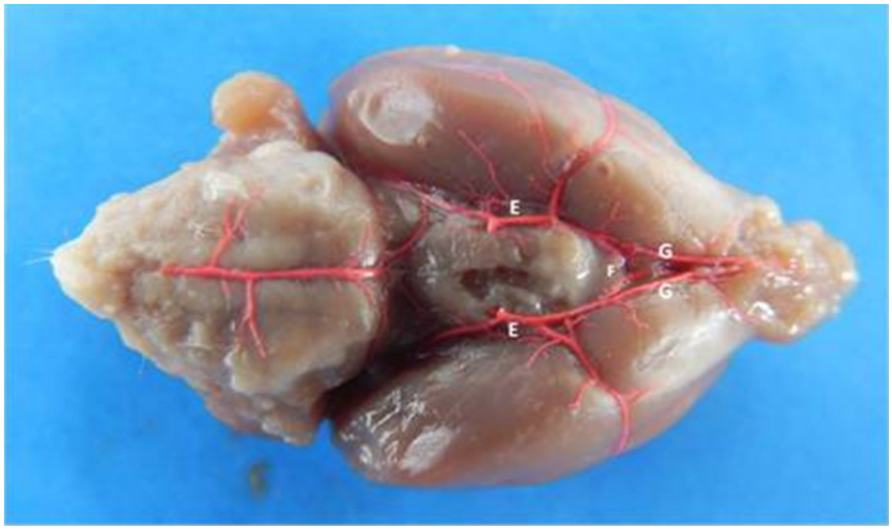

Figure 7. Macroscopic photography of a rat's brain base showing the rostral cerebral artery (E) and its branches: the first branch is housed in the ventral longitudinal fissure (F) and the second one is the internal ophtalmic artery (G).

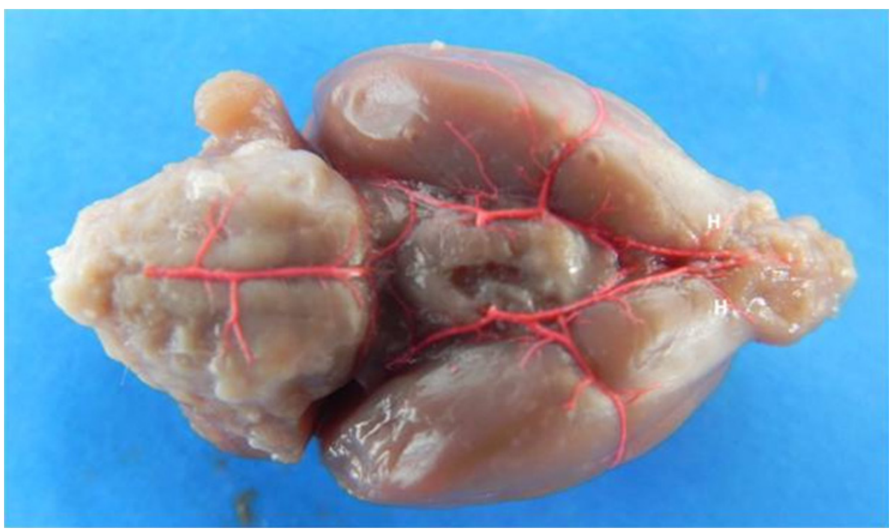

Figure 8. Macroscopic photography of a rat's brain base showing the lateral olfactory bulb artery (H) projecting itself rostrolaterally to nourish the olfactory bulb.

The cerebral arterial circle observed in rat's brain base resulted from the particular arrangement of the rostral and caudal branches of the internal carotid arteries and the terminal branches of the basilar artery. This type of arrangement was also found in hogs by Ferreira and Prada (2005), in white-eared opossums by Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010), in capuchin monkeys by Silva and Ferreira (2002), in dogs by Casal, Arantes, Casimiro et al. (2005) and in chinchillas by Araújo (2004); in the latter, the arterial polygon showed to be closed only posteriorly but opened anteriorly in 70% of the cases.

Nevertheless, the arrangement of the cerebral arterial circle in rats was different from that of equines as described by Prada, Campos, Santos et al. (2003), who demonstrated that the circle was formed by the right and left internal carotid arteries and by the occipital arteries, an event not confirmed in our dissected animals. For studies in hens, Mendoza, Tirado, Figueroa et al. (2009) stated that there was an inter-carotid anastomosis formed by the posterior cerebral artery, from which the basilar artery took its origin, and total absence of the vertebral arteries. This inter-carotid anastomosis is a characteristic feature of birds, also observed in ostriches by Nazer (2009), in which this anastomosis is placed within the sella turcica probably reproducing the function of the cerebral arterial circle that, in these specimens, showed to be always opened rostrally, opened caudally in 80% but closed in the other 20% of the studied brains.

The internal carotid artery arose from the common carotid artery and spread out laterally to the hypothalamus. Araújo (2004) reported the same in chinchillas as well as in dogs and horses. Mendonza, Tirado, Figueroa et al. (2009) described a similar feature in hens, making the exception that the artery's course was close to the tympanum. Ferreira and Prada (2005) related that in hogs the internal carotid artery

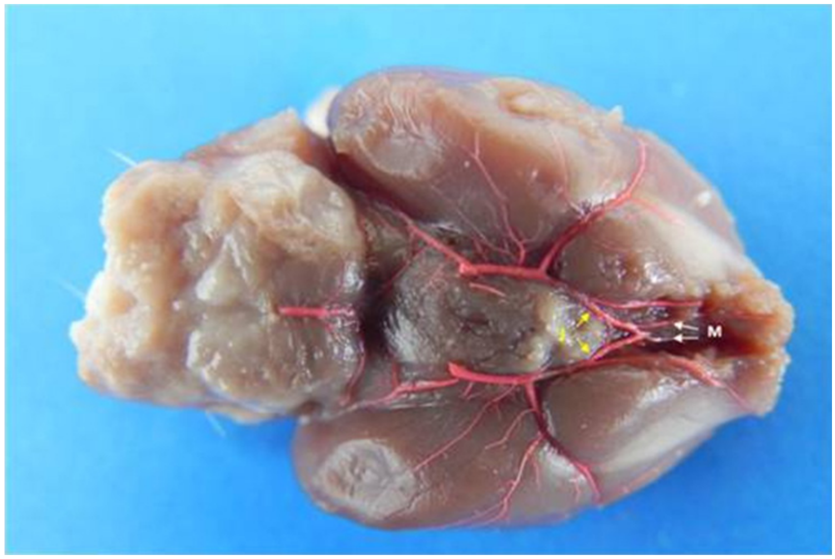

Figure 9. Macroscopic photography of a rat's brain base showing the branches arising from the terminal branch of the rostral cerebral artery: rostral communicating branch (J) and right and left internal ethmoidal arteries (M).

came from the basilar artery's terminal branch which made an anastomosis with the caudal part of the internal carotid artery, the same observed and confirmed by Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010) in white-eared opossums. The internal carotid artery is not mentioned in the studies in capuchin monkeys performed by Silva and Ferreira (2002).

Nazer (2009), studying ostriches, reported that the internal carotid artery, when leaving the cervical carotid canal, divided itself in order to form the external carotid artery and the cerebral carotid artery.

The origin of the internal carotid artery came from the anastomosis between the right and left vertebral arteries and this artery, after coursing rostromedially to the hindbrain, subdivided itself into a rostral cerebellar branch and its terminal branches. This same particular feature has been also described by Araújo (2004) in chinchillas, in capuchin monkeys by Silva and Ferreira (2002), and in hogs by Ferreira and Prada (2005).

In hens, Mendonza, Tirado, Figueroa et al. (2009) related that the basilar artery came from the right caudal cerebral artery and that afterward it formed the ventral spinal artery, different from mammals that had two vertebral arteries, as stated by Nazer (2009) concerning ostriches. Although being a mammal, the white-eared opossum had the basilar artery coming from the ventral spinal artery, as described by Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010). Casal, Arantes, Casimiro et al. (2005), studying dogs, described the basilar artery as a basilar trunk. Ferreira and Prada (2005) reported that the basilar artery came from the vertebral arteries and that it originated the occipital arteries.

The basilar artery emitted collateral branches that were responsible for the blood supply to the bulb, pons and cerebellum. These collateral branches were also present in chinchillas, as stated by Araújo (2004), and a number of them in hogs as described by Ferreira and Prada (2005). Ferreira and Prada (2005) also observed many blood vessels of different sizes in equines. Mendonza, Tirado, Figueroa et al. (2009), in hens, reported them as tiny and few collateral branches. Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010) did not mention collateral branches but it is possible to observe a number of them in brain's photographs. Silva and Ferreira (2002) reported that in capuchin monkeys these collateral branches could be seen coming either from the basilar artery or the vertebral arteries. In ostriches, Nazer (2009) related that these collateral branches formed the main arteries that nourished the cerebellum. The collateral branches were few and small-sized in dogs and were visible in the photographs taken by Casal, Arantes, Casimiro et al. (2005).

Concerning the terminal branches of the basilar artery, Casal, Arantes, Casimiro et al. (2005) reported that the caudal communicating arteries always gave birth to two caudal branches that coursed from rostral to caudal position, named as the caudal cerebral artery and the rostral cerebral artery, respectively. These data were correspondent to those found in our study in rats, as well as those found by Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010) in white-eared opossum, and Ferreira and Prada (2005) in equines. In chinchillas, Araújo (2004) described that the terminal branches coming from the caudal cerebral artery coursed straightly until they reach optic quiasm; Ferreira and Prada (2005) observed in hogs that the terminal branches united themselves to the caudal branches of the internal carotid artery. Differing from these results, Silva and Ferreira (2002) did not mention the caudal cerebral artery in capuchin monkeys, and Mendoza, Tirado, Figueroa et al. (2009) and Nazer (2009) reported nothing about the rostral cerebellar artery in hens and ostriches, respectively.

The middle cerebral artery presented itself as a rostral terminal branch of the internal carotid artery that coursed laterally at the level of the optic quiasm and within the lateral fossa. In its pathway into the lateral fossa, rostral to the pyriform lobe, it emitted many collateral branches for these two anatomical structures and its main trunk branched on the dorsolateral and rostral surfaces of the cerebral hemisphere. The rostral cerebral artery was a terminal branch of the internal carotid artery (right and left), projecting itself rostromedially from the origin of the middle cerebral artery. Its first present collateral branch housed in the ventral longitudinal fissure. These two branches were detailed by Nazer (2009), Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010), Araújo (2004), and Ferreira and Prada (2005).

Araújo (2004), and Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010) reported the presence of the lateral olfactory bulb artery in chinchillas and white-eared opossums, respectively, emerging close to the origin of the single rostral median inter-hemispheric artery. This artery projected itself rostrolaterally in order to nourish the ventrolateral surface of the olfactory bulb. Similarly, this blood vessel was also observed in rats, but it was not mentioned in hogs, equines, ostriches, dogs, hens or capuchin monkeys.

The rostral communicating branch was placed rostrally to the optic quiasm and founding closing the cerebral arterial circle anteriorly. From it emerged the right and left ethmoidal arteries found in rats. This branch was also found in white-eared opossums by Pinto e Silva, Guazzelli Filho, Filadelpho et al. (2010), originating the common artery of the corpus callosum and the olfactory artery. Casal, Arantes, Casimiro et al. (2005) stated that from the caudal communicating arteries in dogs might emerge caudomedial branches that provide the hypothalamic region.

The internal ethmoidal artery was only observed and cited by Araújo (2004) in chinchillas as a branch that formed the terminal branch of the rostral cerebral artery. Its origin was mentioned to be close to the emergence of the medial olfactory bulb artery (when it was not a direct branch) or composing a trunk with the lateral olfactory bulb artery. However, this artery has ever been mentioned by other authors.

5 Conclusions

Resuming, the cerebral arterial circle in rats was formed by branches of the internal carotid artery and basilar artery and it showed to be rostrally closed in all dissected animals by the stable presence of the rostral communicating artery, and caudally by the right and left terminal branches of the basilar artery.

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Received December 10, 2012
Accepted May 24, 2013