The arteries of the brain base in the degu (*Octodon degus* Molina 1782)

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ABSTRACT: The brain arteries derived from 50 adult degu individuals of both sexes were injected with synthetic latex introduced with a syringe into the left ventricle of the heart under constant pressure. After fixation in 5% formalin and brain preparation, it was found that the sources of the brain's supply of blood are vertebral arteries and the basilar artery formed as a result of their anastomosis. The basilar artery gave rise to caudal cerebellar arteries and then divided into two branches which formed the arterial circle of the brain. The internal carotid arteries in degus, except for one case, were heavily reduced and did not play an important role in the blood supply to the brain. The arterial circle of the brain in 48% of the cases was open from the rostral side. Variation was identified in the anatomy and the pattern of the arteries of the base of the brain in the degu which involved an asymmetry of the descent of caudal cerebellar arteries (6.0%), rostral cerebellar arteries (8%) as well as middle cerebral arteries (12%). In 6% of the individuals double middle cerebral arteries were found. In one out of 50 cases there was observed a reduction in the left vertebral artery and the appearance of the internal carotid artery on the same side. In that case the left part of the arterial circle of the brain was supplied with blood by an internal carotid artery, which was present only in that animal.

Keywords: blood supply; brain; arteries; degu; variation

The degu is a rodent of the infraorder Hystricognathi and is indigenous to the south-western part of South America. In Chile it is considered as a pest which damages crops, while in Europe it is used as a lab animal for research into diabetes. In addition, it is now bred as a companion animal. Numerous publications have described the blood supply to the brain in representatives of the infraorder Hystricognathi. Gielecki et al. (1996) investigated the metrics of the arterial circle of the brain and the basilar artery using digital image analysis. Additionally, the anatomy and variation of the arteries in the capybara (Reckziegel et al. 2001), otter (Skoczylas et al. 2012) and coypu (Azambuja 2006), have all been described. All the species of this infraorder investigated so far show a similar blood supply to the brain; namely, the main sources of blood supply to the brain are vertebral arteries and the basilar artery, formed as a result of its anastomosis, which in its final section bifurcates into symmetrical branches forming the arteries of the base of the brain. A significant reduction or even complete lack of internal carotid arteries, which in other mammalian species, including humans, constitute the second source of blood supply to the brain, is characteristic of the species from this group. In ruminants, internal carotid arteries formed as an intracranial section, which formed from epidural rete mirabile, constitute the main source of blood to the brain (Brudnicki 2000; Frackowiak and Jakubowski 2008; Brudnicki 2012).

In the available literature there is no information on the blood supply to the brain in the degu and so the present study was conducted to address this gap. The observations reported here will contribute to research on comparative anatomy and the phylogenetic development of the blood supply to the central nervous system.

MATERIAL AND METHODS

The study was conducted on 50 degu brains derived from adult individuals of both sexes. The arteries were filled with synthetic latex LBS 3060 introduced with a syringe into the left ventricle of the heart under constant pressure. After fixation in 5% formalin solution, the skin and head muscles were removed, the skulls were decalcified in 5% hydrochloric acid and then the brains were taken out of the skull cavity. The arteries were prepared under a stereoscopic microscope and then photographed using a Nikon D90 (12.9 MPX) camera. Diagram drawings of the arteries of the base of the brain and the brunches were also made. Vessels were named according to the Nomina Anatomica Veterinaria (2005), and some designations are based on the authors' interpretation of earlier publications. Some specimens were photographed to illustrate the documentation. The occurrence of vessel variants has been expressed as a percentage of the total number of brain specimens studied (50).

RESULTS

The brain in the degu was supplied with blood by vertebral arteries descending from symmetrical subclavian arteries. The right and the left vertebral artery, having ascended through the foramen magnum, became anastomosed and formed the basilar artery, which was large in diameter. The basilar artery went along the ventral median fissure of the medulla oblongata, until the anterior border of the pons where it forked out into right and left terminal branches. Along its course, the basilar artery gave rise to numerous symmetrical branches onto the medulla oblongata, and then caudal cerebellar arteries. The caudal cerebellar arteries usually gave off labyrinthine arteries. Above the orifice of the caudal cerebellar arteries, there descended successive minor arterial branches onto the pons. Having passed the anterior border of the pons, the basilar artery bifurcated into two branches which, running around the pituitary gland, mammillary body and optic chiasm along the medial surface of the pyriform lobes, formed the arterial circle of the brain.

The anatomical nomenclature of the arteries of the base of the brain was based on the names of the arteries described in humans and most mammalian species where internal carotid arteries have a considerable share in the blood supply to the brain. When naming the different vessels the peculiarities of the blood supply to the brain observed in the Infraorder Hystricognathi, which also includes the degu, were not considered. With the above in mind, the arterial branches formed as a result of the division of the basilar artery corresponding to the location of caudal communicating arteries will from here be described in the paper in that way until the descent of reduced internal carotid arteries.

From the initial section of caudal communicating arteries there bifurcated symmetrically single rostral cerebellar arteries. Slightly more rostrally there descended symmetrically, with a single trunk, caudal cerebral arteries. A short trunk divided then into vessels running towards the inside of the transverse cerebral fissure. The caudal branch gave rise to the tectal artery, which reached as far as the promontories. It also gave rise to branches reaching the diencephalon and was running further as an intrahemisphere caudal artery. The terminal branches bordered with the splenium of the corpus callosum, forming an anastomosis with the terminal branches of the rostral branch inside the intrahemisphere rostral central artery. The rostral branch gave rise to cortical branches to the caudal medial part of the pyriform lobe.

The successive branch consisted of thin branches corresponding to the location of internal carotid arteries. They were usually arc-bent and rostrally they gave rise to internal ophthalmic arteries which formed on the ventral surface of optic nerves. The descent of internal carotid arteries designated an agreed-on border between caudal communicating arteries and rostral cerebral arteries. Rostral cerebral arteries were a continuation of caudal communicating arteries. In their initial section, they produced symmetrically thin rostral choroidal arteries which ascended under the pyriform lobe. The next branches coming from rostral cerebral arteries were middle cerebral arteries. They descended symmetrically with a single trunk which then divided into cortical branches supplying blood to both hemispheres (Figure 1).

Having produced middle cerebral arteries, rostral cerebral arteries gave rise to internal ethmoidal arteries and then they ascended under optic nerves and went towards the longitudinal cerebral fissure where they became anastomosed and created a single corpus callosum artery. Internal ethmoidal arteries went along the internal border of olfactory tracts and reached olfactory bulbs. The corpus callosum artery was formed ss a result of the anastomosis of the rostral cerebral arteries. The artery ascended into the longitudinal cerebral fissure, formed an arc around the genu of the corpus callosum and ran caudally above the diaphysis of the corpus callosum giving rise to numerous branches

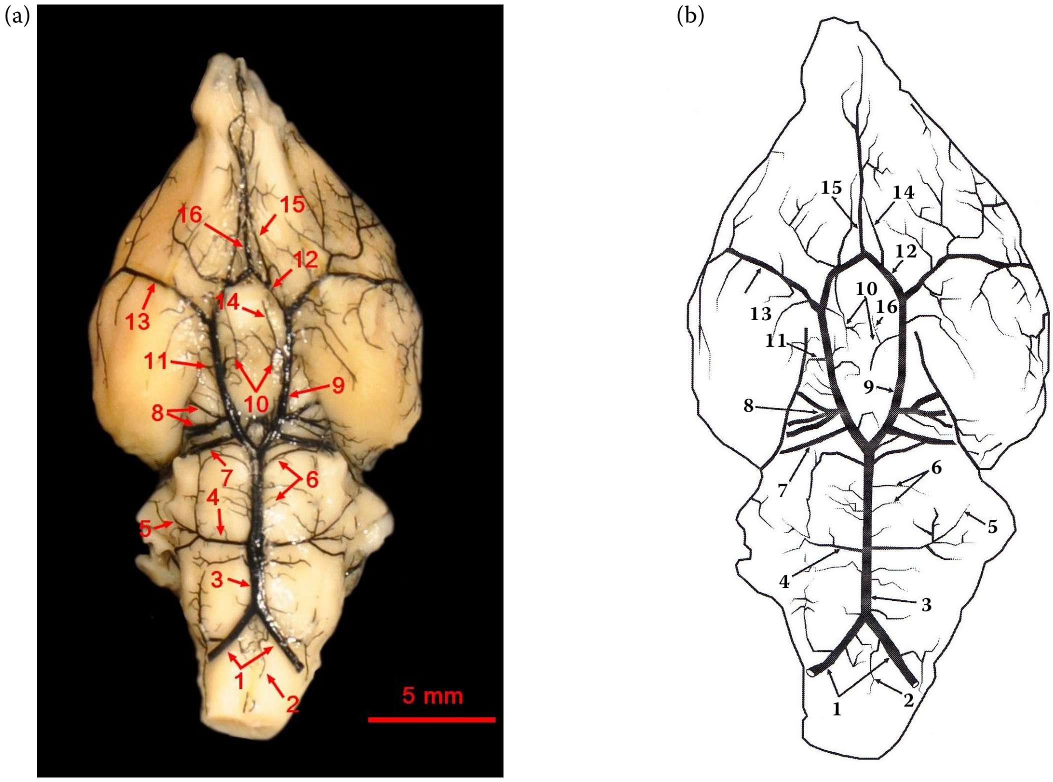

Figure 1. Arteries of the base of the brain in the degu (a) and diagram (b). 1 = vertebral artery, 2 = ventral spinal artery, 3 = basilar artery, 4 = caudal cerebellar artery, 5 = labyrinthine artery, 6 = pontine and medulla oblongata branches, 7 = rostral cerebellar artery, 8 = caudal cerebral artery, 9 = caudal communicating artery, 10 = internal carotid artery, 11 rostral choroid artery, 12 = rostral cerebral artery, 13 = medial cerebral artery, 14 = internal ophthalmic artery, 15 = internal ethmoidal artery, 16 = callosal artery

onto the left and right medial surface of cerebral hemispheres. The branches then left the longitudinal cerebral fissure until they reached a small longitudinal area of the dorsal part of the brain and formed an anastomosis with the terminal branches of the middle cerebral artery. The cortical branches descending from the caudal section of the corpus callosum artery, on the other hand, were anastomosed with the terminal branches of the caudal cerebral arteries.

Variation concerning the pattern, the way of descent and the asymmetry in the anatomy of respective arterial vessels was observed in the degu.

Vertebral arteries in three (6.0%) individuals showed differences in thickness. The right-side artery was a well developed vessel, whereas the left-side artery was very thin. In six (12.0%) individuals in the initial section of the basilar artery slightly below the descent of caudal cerebellar arteries a vascular islet was observed. Caudal cerebellar arteries in three (6.0%) individuals descended from the basilar artery asymmetrically. Rostral cerebral arteries usually came symmetrically from caudal communicating arteries. In four (8%) individuals, in three on the left and in one on the right, asymmetrical rostral cerebral arteries descended from the basilar artery. In those cases the descent of rostral cerebral arteries was asymmetrical. One of the arteries descended from the basilar artery and the other from the caudal communicating artery (Figure 2).

Caudal cerebral arteries usually descended symmetrically with a single trunk which bifurcated into two vessels. In three (6%) individuals on the left there descended independently two caudal cerebral arteries. Caudally, the supine artery divided similarly as observed in other cases, the rostrally-descending artery ascended under the pyriform lobe and gave rise to terminal branches to the caudal medial part of the pyriform lobe.

The middle cerebral artery in three (6.0%) individuals was a double vessel. In six (12%) cases the descent of middle cerebral arteries was asymmetrical.

Rostral cerebral arteries medially produced cephalad communicating arteries which became anastomosed before reaching the median fissure of the brain into the corpus callosum artery; they them-

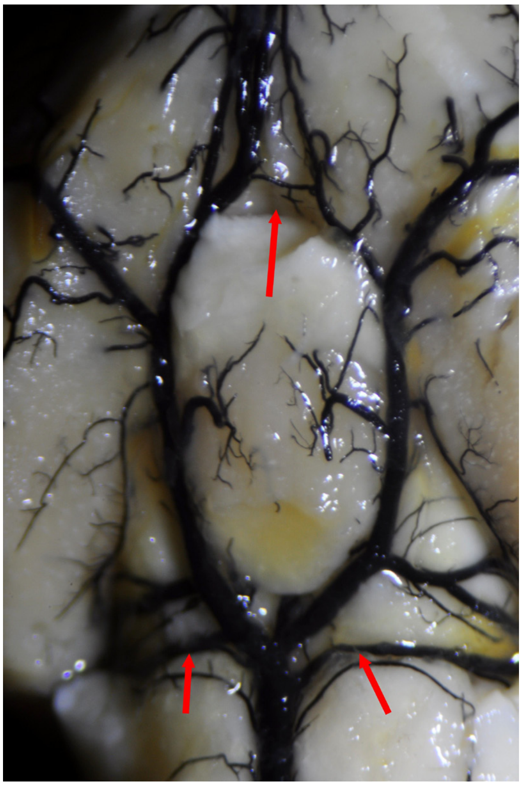

Figure 2. Asymmetry of the descent of rostral cerebral arteries

selves, however, continued into internal ethmoidal arteries. In 24 (48%) individuals, from the rostral side there was noted an open arterial circle of the brain. In those cases the artery of the corpus callosum descended from one of the rostral cerebral arteries.

Among 50 degu brains one special case of blood supply to the brain was observed. The brain of that individual was supplied with blood by the right vertebral artery which then changed into the basilar artery. The left vertebral artery was very heavily reduced and was present in the form of a minor arterial twig. The basilar artery produced symmetrical caudal cerebellar arteries and then asymmetrical rostral cerebellar arteries. The left rostral cerebellar artery descended from the basilar artery. Slightly rostrally on the same side the caudal cerebral artery descended. On the right the basilar artery became transformed, without a clear border, into the right caudal communicating artery which, in turn, produced the rostral cerebellar artery and the caudal cerebral artery. On the same side, medially, a minor arterial vessel descended, the location of which corresponded to that of the internal carotid artery. At the same level, towards the pyriform lobe, the rostral choroidal artery separated. In agreement with Nomina Anatomica, the artery running rostrally to the descent of the internal carotid artery was designated as the rostral cerebral artery. The thickest branch of the rostral cerebral artery was the right middle cerebral artery. Above its descent, the internal ethmoidal artery separated. The rostral cerebral artery changed into the rostral communicating artery which produced the corpus callosum artery ascending into the cerebral median fissure. It itself continued on to the left hemisphere. On the left the internal carotid artery was observed. Out of the 50 brains studied, the presence of the internal carotid artery was observed only in a single case. The artery ran along the internal surface of the pyriform lobe, it produced the left middle cerebral artery and then, without a clear border, it anastomosed with the rostral communicating artery. Between the initial section of the internal carotid artery and the caudal cerebral artery, there ran a thin arterial anastomosis from the caudal side closing the arterial circle of brain. Its location corresponded to the location of the left caudal communicating artery (Figure 3).

Figure 3. The case of variability or brain base arteries = Reduced left vertebral artery and occurrence of the left internal carotid artery. 1 = reduced left vertebral artery, 10 = occurrence of the left internal carotid artery

DISCUSSION

The blood supply to the brain in the degu is mostly determined by the system of vertebral arteries. Such a brain blood supply type has been defined as type III. Indeed, vertebral arteries play a decisive role and are often the only means of supplying blood to the brain in all representatives of infraorder Hystricognathi investigated so far, such as the guinea pig (Kabak and Haziroglu 2003), coypu (Azambuja 2006) and capybara (Reckziegel et al. 2001). In such a mode of blood supply the basilar cerebral artery, at the height of the anterior border of the pons is divided into two terminal branches, the location of which correspond to that of caudal communicating arteries and are therefore referred to as such in the literature. From the initial sections of those arteries there descend rostral cerebellar arteries. In 8.0% of individuals asymmetry was identified in the descent of rostral cerebellar arteries. One of the arteries descended from the caudal communicating artery, while the other became separated from the basilar artery. Asymmetries in the separation of rostral cerebellar arteries were described in the rabbit (Brudnicki et al. 2012; de Souza and Campos 2013). The descent of the rostral cerebellar artery varies between species. In coypu Azambuja (2006), the rostral cerebellar artery, in most cases, constitutes a single vessel and descends similarly as in the degu and capybara, from the caudal communicating artery. In rodents and also in the muskrat (Jablonski and Brudnicki 1984), in most cases the rostral cerebellar arteries constitute the terminal branches of the basilar artery. Caudal cerebral arteries separate symmetrically with a single trunk which then bifurcates into two arterial vessels. Only in 6% of individuals was there found, as well as the typical descent, a rostral separation of the other caudal cerebral artery on the left. Multiple caudal cerebral arteries are found as a rule in even-toed ungulates (Brudnicki 2000; Brudnicki 2011). The internal carotid artery is not a source of blood supply to the brain in the degu. Except for a single case, a thin vessel, descending symmetrically from caudal communicating arteries can be considered to be reduced internal carotid arteries which play a function distinct from supplying the arterial circle of the brain with blood. According to some authors, the arterial carotid artery disappears in some species; for example, only a thin fibrous tract was observed in capybara (Reckziegel et al. 2001), while in the coypu it was completely absent (Azambuja 2006).

Multiple middle cerebral arteries were encountered in the degu in 6.0% of cases. Brudnicki et al. (2012) and de Souza and Campos (2013) identified multiple middle cerebral arteries in 36.5% of wild rabbits and 20% of New Zealand rabbits, respectively. The arterial circle of the brain, open from the rostral side, was described in the degu in 48% of individuals, and was also encountered in other species. In the coypu it was described by Azambuja (2006). In these two species it was open in most cases, whereas in the capybara (Reckziegel et al. 2001), the arterial circle of the brain was open in only a few cases. An open arterial circle of the brain was described by de Souza and Campos (2013) in 6.7% of rabbits and by Brudnicki et al. (2012) in 5.26% of the cases studied.

There is one mode of blood supply to the brain described here, which is especially noteworthy. In this case, a reduced left vertebral artery occurred together with the appearance of the internal carotid artery on the same side. The left part of the arterial circle of the brain was supplied with blood by the internal carotid artery present only in that case. The right side of the arterial circle was supplied by the right vertebral artery and the basilar artery, as its prolongation. On the left the internal carotid artery was not present, similarly as in all the other brains studied here. In such cases there was noted a considerable increase in the diameter of caudal communicating arteries and vertebral arteries, together with the basilar artery, through the caudal communicating arteries, forming the main path of the brain's supply of blood. From the analysis of the described case, it seems that the retardation of the left vertebral artery of the brain in that individual triggered a second source of blood supply in a form of the left internal carotid artery. In its traditional form, the left caudal communicating artery closes on the side the arterial circle of the brain and acts as a regulator of blood flow as well as a pressure corrector for blood reaching the brain through the left internal carotid artery and the right vertebral artery.

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Received: 2014–05–25
Accepted after corrections: 2014–08–25

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