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Early View

Original Research Article

The Arteries of the Encephalon Base in the Selected Representatives of the Suiformes and Hippopotamuses

Key words

brain base arteries;
desert warthog;
hippopotamus;
neuroanatomy

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Abstract: The article provides general biological facts, which can be used to discuss the taxonomy of species, as well as information which may be useful for veterinarians working in zoos or saving and protecting wild animals in their natural environment. The aim of the study was to compare and describe the anatomy of the arteries of the encephalon base of the representatives of the Suiformes suborder and Hippopotamuses. Desert warthogs, Eurasian wild boars, collared peccaries, pygmy hippopotamuses and common hippopotamuses were analysed. Two research methods were used: corrosion casts of blood vessels were made after injecting stained vinyl superchloride into the common carotid arteries, and manual preparations were made after injecting stained latex and fixing in formalin. The research showed some common traits for all species of the Suiformes and Hippopotamuses, while maintaining distinctiveness at the family level. In the cranial cavity, the internal carotid artery divides into the rostral cerebral artery and the caudal communicating artery, forming the cerebral arterial circle, whose shape and vessel arrangement vary between species: figure-eight in wild boars and peccaries, flattened in warthogs, and triangular in hippopotamuses. The caudal arteries connect to the basilar artery, which is particularly large in hippopotamuses, and some vessels show unilateral or asymmetrical variations. Key findings are that the diameter of the rostral cerebral arteries are larger than the caudal part of the cerebral arterial circle, which varies in shape, and that the basilar artery is enlarged in hippopotamuses compared to Suiformes.

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Introduction

Suiformes, Ruminantia and Tylopoda are three suborders within the Artiodactyla order, which is one of the most numerous taxa of contemporary mammals (1, 2).

Arterial circle of the brain (The Circle of Willis) is a ring-shaped arterial structure at the base of the brain whose main function is to ensure a constant and uniform blood supply to the brain. In mammals, including pigs, this circle is supplied by several major arterial sources; however, their anatomy can vary significantly between species. In pigs, a particularly important role in delivering blood to the Circle of Willis is played by the rostral epidural rete mirabile *(rete mirabile epidurale rostrale)*, which acts as the main connection between the carotid arterial system and the cerebral circulation. Importantly, in this species, the cranial cerebral arteries may join at the midline and form a single trunk, which is one of the characteristic anatomical features of cerebral vascularization. In a broader sense, the Circle of Willis in pigs is therefore not merely a classical "ring" of arteries, but rather a component of a more complex vascular system (3).

The arteries of the encephalon base in artiodactyls have been described in numerous species of ruminants, including domesticated and wild animals, e.g. deer and numerous antelopes (3-9) and in camels (Camelidae), species of Old and New World camelids, the only extant animals of the Tylopoda suborder (10-17). The arterial pattern of the encephalon base in species of the Suiformes suborder has been investigated in the domestic pig of the Suidae family – both in adult animals (18-21) and in foetuses (22, 23). There has also been comparative research on this vascular area in the Eurasian wild boar, i.e. the wild ancestor of the domestic pig (24).

One of the species described in this study is the pygmy hippopotamus, which is marked as endangered on the Red List of threatened species of the International Union for Conservation of Nature (IUCN Red List). Currently its population is estimated at 2,000-2,499 and it exhibits a downward trend (25). The common hippopotamus seems to be in a better situation, as its population is estimated at 115,000-130,000. The population trend is stable (26), although the species is marked as vulnerable on the IUCN Red List. Of the other species described in this study, only the warthog population exhibits a downward trend, although the animal is in the least concern group (27). According to earlier classifications, hippopotamuses were included in Suiformes; however, more recent studies, including genetic analyses, indicate that they should be classified as Whippomorpha, as they have been shown to be more closely related to whales than to pigs (28, 29).

The aim of the study was to describe and compare the anatomy of the arteries of the encephalon base of the selected representatives of the Suiformes suborder and Hippopotamidae. The article provides general biological facts, which can be used to discuss the taxonomy of species, as well as information which may be useful for veterinarians working in zoos or saving and protecting wild animals in their natural environment. The maintenance of species diversity and the prevention of extinction should be our common goal, contributing to the protection of the environment for our common good and for future generations. Therefore, it seems that any information that may contribute to more effective protection of endangered species is extremely valuable. This is also anatomical information, which is essential for clinical activity, especially in surgery and basic interventions following injuries in accidents or poaching.

Material and methods

The study was conducted on 27 adult animals of both genders. Sex had no influence on the vascular anatomy, and no sexual dimorphism affecting the anatomical findings was observed. The following animals were analysed: the Suidae family: 6 desert warthogs (*Phacochoerus aethiopicus*), 10 Eurasian wild boars (*Sus scrofa*); the Tayassuidae family: 6 collared peccaries (*Pecari tajacu*); the Hippopotamidae family: 2 pygmy hippopotamuses (*Hexaprotodon liberiensis*) and 3 common hippopotamuses (*Hippopotamus amphibius*). The analyzed cadavers were obtained as post-mortem material from zoos, and were obtained through hunting.

Twenty-two preparations were obtained as follows. A stained solution of vinyl superchloride was injected into the bilateral common carotid arteries. When it hardened after a short time, the preparations were enzymatically macerated with Persil powder (Henkel, Düsseldorf) at 40 °C for about one and a half months. In this way corrosion casts of vessels on the bone scaffold were obtained. Another method was used to obtain 5 other preparations (two Eurasian wild boars, one collared peccaries, one desert warthog, one common hippopotamus) . Liquid LBS 3060 stained latex was injected into the bilateral common carotid arteries. When it hardened in 5% formalin solution, the blood vessels were prepared manually with surgical instruments. Thus, images of the blood vessels on the tissues of individual animals were obtained. The names of anatomical structures were standardised according to the Nomina Anatomica Veterinaria (2017) (30).

Results

In the cranial cavity, the intracranial segment of the internal carotid artery (*arteria carotis interna*) emerges from the arteries of the rostral epidural rete mirabile (*rete mirabile epidurale rostrale*). This segment finally divides into the main components of the arterial circle of the brain, i.e. the rostral cerebral artery (*arteria cerebri rostralis*) and the caudal communicating artery (*arteria comminicans caudalis*).

The arterial circle of the brain is figure-eight-shaped in the Eurasian wild boar and collared peccari (Fig.1 and 2).

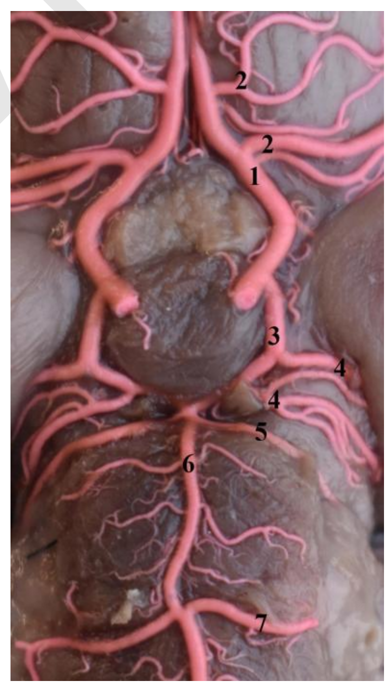

Figure 1: Arterial circle of the brain in the Eurasian wild boar. Latex preparation. 1 – The rostral cerebral artery 2 – The middle cerebral artery 3 – The caudal communicating artery 4 – The caudal cerebral artery 5 – The rostral cerebellar artery 6 – The basilar artery 7 – The caudal cerebellar artery

Figure 2: Arterial circle of the brain in the collared peccary. Corrosion cast. 1 – The rostral cerebral artery 2 – The middle cerebral artery 3 – The caudal communicating artery 4 – The caudal cerebral artery (please note the presence of a duplicated vessel) 5 – The basilar artery 6 – The rostral cerebellar artery 7 – The caudal cerebellar artery 8 – The rostral choroid artery

The rostral part of the arterial circle of the brain is composed of the bilateral rostral cerebral arteries. It is larger and protrudes more to the sides. The caudal part of the circle is composed of the bilateral caudal communicating arteries anastomosed with the unpaired basilar artery (*arteria basilaris*). In the desert warthog, the arterial circle is flattened cranio-caudal, which is most marked on the caudal side (Fig .3). In addition, the caudal communicating arteries in the initial section are arranged sagittally to each other. At the point where the caudal cerebral artery branches off, the caudal communicating arteries change direction and arrange themselves convergently.

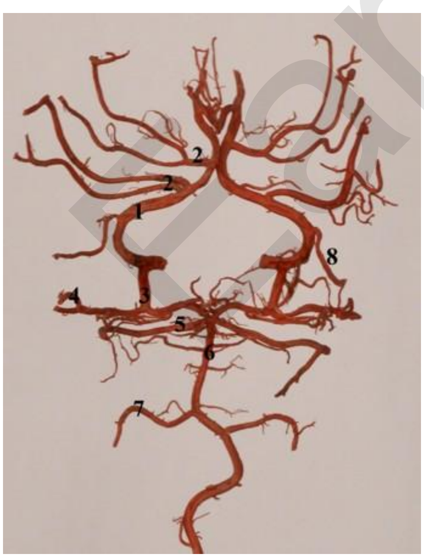

Figure 3: Arterial circle of the brain in the desert warthog. Corrosion cast. 1 – The rostral cerebral artery 2 – The middle cerebral artery 3 – The caudal communicating artery 4 – The caudal cerebral artery (please note the presence of a duplicated vessel) 5 – The rostral cerebellar artery 6 – The basilar artery 7 – The caudal cerebellar artery 8 – The rostral choroid artery

In hippopotamuses, the arterial circle of the brain was elongated and assumed a triangular shape (Fig. 4), with the base of the triangle directed rostrally. Only in one case of pygmy hippopotamus the caudal communicating arteries were taking shape as described in the desert warthog. The rostral part of the cerebral arterial circle in the vascular variant in one pygmy hippopotamus was not gently curved but it was conical.

The diameter of the rostral cerebral arteries is larger than the caudal part of the circle in the desert warthogs, Eurasian wild boars and peccaries. Such big differences in the vessel diameter were not observed in the hippopotamuses. The caudal part of the arterial circle of the brain is more slender. The diameters of the vessels in this part are much smaller than the arteries in the rostral part of the arterial circle, with the exception of hippopotamuses. The caudally located section of the caudal communicating artery has a larger diameter in this species than the section of this vessel located rostrally. A distinctly larger diameter is evident up to the point where the caudal cerebral artery branches off.

Figure 4: Arterial circle of the brain in the common hippopotamus. Corrosion cast. 1 – The rostral cerebral artery 2 – The middle cerebral artery 3 – The caudal communicating artery 4 – The caudal cerebral artery (please note the presence of a duplicated vessel) 5 – The rostral cerebellar artery 6 – The basilar artery 7 – The caudal cerebellar artery 8 – The rostral choroid artery

The rostral cerebral artery is the vessel with the largest diameter in all the species under study. It is C-shaped. The bilateral vessels run next to each other rostrally from the optic chiasm. They run along the longitudinal cerebral fissure and branch to the rostral parts of the encephalon. They extend into the internal ethmoid artery in all the species, except hippopotamuses. In one pygmy hippopotamus the rostral cerebral artery was a bilateral, double vessel from the place where the middle cerebral artery branched. The bilateral rostral cerebral arteries are connected by a thin rostral communicating artery. One peccary did not have this vessel. As a result, the cerebral arterial circle of this animal was open.

The middle cerebral artery branches from the point located at two-thirds of the length between the final division of the intracranial segment of the internal carotid artery and the place where the rostral cerebral artery bends into the longitudinal cerebral fissure. The middle cerebral artery is a strong vessel. Its diameter is not much smaller than that of the cerebral rostral artery. It extends from the rostral side of the piriform lobe onto the dorsolateral surface of the cerebral hemisphere. This vessel had a number of branches. Usually this vessel branched off as a double artery. In one Eurasian wild boars bilaterally, one collared peccary unilaterally, and one pigmy hippopotamus unilaterally it was single vessel, which further divided very close to the branching point.

Next, the rostral choroid artery branches off from the rostral cerebral artery. It is a single vessel branching close to the place where the intracranial segment of the internal carotid artery divides into the main components of the arterial circle of the brain.

The first branch of the caudal communicating artery is the caudal cerebral artery (*arteria cerebri caudalis*). It is a double vessel. The first, which is located more rostrally, usually has a larger diameter. It was a triple vessel in two Eurasian wild boars bilaterally, one Eurasian wild boar unilaterally, one desert warthog unilaterally, and one collared peccaries unilaterally. It was a single vessel in one common hippopotamus unilaterally. Its diameter was as large as that of the middle cerebral artery.

The rostral cerebellar artery (*arteria cerebelli rostralis*) is the next vessel which branch off from the arterial circle of the brain. It is a single vessel. Its diameter is similar to the diameter of the first (rostral) caudal cerebral artery. A double bilateral form of this vessel was found in one peccary, which was an individual-specific variety.

The basilar artery is the vessel that anastomoses the bilateral caudal communicating arteries. The diameter of this vessel does not exceed the diameter of the caudal communicating artery or it is slightly weaker. The exception is hippopotamuses, in which this vessel has a very large diameter, much larger than the caudal communicating arteries, especially in their rostral section. Its course is sigmoid. The diameter of this vessel does not change along its entire length. It was the least sigmoid in the hippopotamuses. The basilar artery anastomoses to the vertebral arteries. The basilar artery in the vascular variety formed a vascular loop in one pygmy hippopotamus and two Eurasian wild boars.

The caudal cerebellar artery (*arteria cerebelli caudalis*) is the vessel branching off from the basilar artery. In most cases it was a single vessel. It was a double vessel in two wild boars, one warthog and one peccary. The vessels on the right and left side usually deviated asymmetrically.

Table 1: Summary of the essential features of the main vessels

Structure	Eurasian wild boar	Collared peccary	Desert warthog	Common hippopotamus	Pygmy hippopotamuses
Shape of cerebral arterial circle	Figure-eight	Figure-eight	Flattened anteroposteriorly	Usually triangular	Usually triangular
Rostral cerebral artery	Largest diameter, C-shaped	Largest diameter, C-shaped	Largest diameter, C-shaped	Does not continue into the internal ethmoidal artery	As in the Common hippopotamus; double in 1 specimen
Rostral communicating artery	Present	Absent in 1 specimen (open arterial circle)	Present	Present	Present
Middle cerebral artery	Usually double; single bilaterally in 1 specimen	Usually double; single unilaterally in 1 specimen	Double	Double	Usually double; single unilaterally in 1 specimen
Rostral choroid artery	Single	Single	Single	Single	Single
Caudal cerebral artery	Usually double; frequent triple variants	Usually double; triple variant present	Usually double; triple variant present	Single in 1 specimen	Double
Rostral cerebellar artery	Single	Single; double bilaterally in 1 specimen	Single	Single	Single
Caudal communicating artery	Slender posterior part	Slender posterior part	Initially parallel, then converging	Posterior segment wider than anterior	As in the Common hippopotamus
Basilar artery	S-shaped; vascular loop in 2 specimens	S-shaped	S-shaped	Very large diameter, least S-shaped	Vascular loop in 1 specimen
Caudal cerebellar artery	Usually single; double in 2 specimens	Usually single; double in 1 specimen	Usually single; double in 1 specimen	Usually single	Usually single

Discussion

Due to the article category and "brief communication" requirements, we touched on the most important issues in the discussion section.

The main vessels (Tab. 1) that make up the circle of Willis, in all analysed animals derived from the final division of the intracranial segment of the internal carotid artery emerging from the rostral epidural rete mirabile, while in the camels, directly from the vessels of the rostral epidural rete mirabile (12, 13, 16, 17).

In ruminants the caudal segment of the basilar artery becomes thinner and thinner, e.g. in representatives of the Antilopinae subfamily (4), the Caprinae subfamily (5, 17, 31, 32) (in domestic goat *(Capra hircus)* the basilar artery originates at the prepontine sulcus, runs caudally over the pons and medulla oblongata, gives pontine, caudal cerebellar and medullary branches, and continues as the ventral spinal artery) (32), species of the nilgai, nyala and common eland genera (33), giraffe (34), red deer (35) and European roe deer (36). Baldwin and Bell (37, 38) state that blood was not supplied from the vertebral arteries to the encephalon through the basilar artery. In the analyzed species, the basilar artery does not have such a feature as described above. The basilar artery plays a completely different role in some species of rodents, where the lumen of the internal carotid artery becomes obliterated or remains very narrow and is only minimally involved in the supply of blood to the cerebral arterial circle or it does not supply blood at all. The fact that the basilar artery supplies as much as 60% of blood to the cerebral arterial circle is very suggestive evidence confirming its role as the main source of blood for the encephalon of the guinea pig (39). Researchers have also described a strong basilar artery in the crested porcupine (40), Cairo spiny mouse (41), common degu (42), nutria (43), European ground squirrel (44), long-tailed chinchilla (45), red squirrel (46), as well as the European rabbit and the European hare of the Lagomorpha order (47, 48).

The shape of the cerebral arterial circle differs slightly in the analyzed species. The rostral part of the cerebral arterial circle in Eurasian elk resembles a circle more than an ellipse (8), compared to Bovini. The bilateral caudal connecting arteries in the banteng converge at a less acute angle than in other Bivini. The shape of the entire cerebral arterial circle can be described as heart-shaped, which has also been observed in other bovids (4). In the savannah giraffe, the shape of the cerebral arterial circle is almost triangular (34). In camels, on the other hand, it resembles the number "8" (17).

To sum up, it can be stated that: Differences in the structure of the cerebral arterial circle have been demonstrated between representatives of Suiformes and Hippopotamuses, as well as between given species. The diameter of the rostral cerebral arteries in Suiformes is larger than that of the caudal part of the cerebral arterial circle, which shows considerable variation in shape. The diameter of the basilar artery differs between the two groups.

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Ethics approval

All applicable international, national, and institutional guidelines for the care and use of animals were followed.

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