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Arterial vascularization in the giraffe brain

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The aim of this study was to analyze the system of arteries in the brain of the giraffe, including the arterial circle of the brain, its branches and junctions, as well as individual variation of the vessels. Analyses were performed on postmortem material of 12 heads of giraffes obtained from Polish zoological gardens. The age of the examined animals ranged from 1.5 to 12 years. Moreover, arteries of one fetus aged approximately 10 months were also analyzed. Arteries of the heads were injected with latex and vinyl superchloride dissolved in acetone. In the giraffe, similarly as in other ruminant species, obliteration of the intracranial segment of the internal carotid artery was observed, together with the presence in the cranial cavity of the rostral epidural rete mirabile, from which the preserved intracranial segment of the internal carotid artery exteriorizes. The rostral cerebral artery of the brain and the caudal communicating artery, participating in the formation of the arterial circle of the brain, are formed by segments of the terminal intracranial part of the internal carotid artery. In the giraffe branches of the arterial circle of the brain included: the internal ethmoidal artery, the middle cerebral artery, the rostral choroid artery, the caudal cerebral artery, the rostral cerebellar artery and the caudal cerebellar artery. It was shown that the basilar artery was thin and could not participate in the blood supply for the brain. On the basis of the conducted analysis it was found that in the giraffe the arterial circle of the brain is supplied with blood mainly by the maxillary artery.

Introduction

The description of the system of arteries in the brain of the giraffe, *Giraffa camelopardalis*, fills another gap in comparative studies on the system of arteries of the brain in even-toed ungulates (Artiodactyla) by the inclusion of a representative of the Giraffidae family from the suborder Ruminantia. Some aspects of the vascular system in the giraffe were analyzed by Goetz (1955), and Goetz and Keen (1957), while arteries of the head in this species were described by Frąckowiak and Godynicki (1979).

Study of the arterial pattern in the giraffe brain and connections of these vessels may by useful in the interpretation of results of experiments and discussion about blood supply in this area of the central nervous system. Features of the vascular system are also useful in designing taxonomic classification based on the comparison of many features of organisms (Shoshani & McKenna 1998).

The aim of this study was to characterize the system of arteries in the brain of the giraffe, including the arterial circle of the brain, its branches and junctions, as well as individual variation within the analyzed vascular area. Features that might be useful in taxonomy were also included.

Material and methods

Analyses were conducted on 12 heads of giraffes donated by the Wielkopolska Zoological Park in Poznań and the Zoological Garden in Płock. The examined animals were between 1.5 and 12 years of age, while one giraffe foetus showed intrauterine age of approximately 10 months. Arteries in the heads were filled with latex and stained vinyl superchloride dissolved in acetone, by injections via the two common carotid arteries. Corrosion casts were prepared from ten heads, while two heads, the arteries of which were filled with latex, were prepared manually. The course, segmentation, junctions and location of vessels in relation to the bones of the skull were examined in all specimens. The topography of arteries in relation to the brain was investigated on latex specimens. Nomina Anatomica Veterinaria (1994) was used in the nomenclature of vessels.

Results

In the giraffe, arteries supplying the brain branch off the arterial circle of the brain, formed by segmentation of the terminal intracranial part of the internal carotid artery.

During ontogenesis the internal carotid artery undergoes far-reaching transformations, leading to complete obliteration of its intracranial segment and, as a consequence, to loss of junction with the common carotid artery. The preserved intracranial segment of the internal carotid artery was surrounded by dense arteries of the rostral epidural rete mirabile (the intraretal segment) and, then, as a supraretal segment it projected from the rete and underwent final segmentation into vessels forming the arterial circle of the brain. Terminal parts of the intraretal segment of the internal carotid artery were anastomosed via the caudal intercarotid artery.

Bilateral rostral cerebral arteries of the brain from the anterio-lateral side, and caudal communicating arteries from the postero-lateral side together with the basilar artery formed the arterial circle of the brain.

The rostral epidural rete mirabile (Fig. 1) was supplied mainly by the rostral branches branching off the maxillary artery and the caudal branch to the rostral epidural rete mirabile. Moreover, a thin condylar artery branching off the occipital artery joined the rete.

In the examined giraffes, the shape of the arterial circle of the brain, in spite of individual differences (Fig. 2), was almost triangular.

Branches to individual brain structures stemmed off from segments of the arterial circle of the brain.

A single rostral choroid artery branched off the initial segment of the rostral cerebral artery. Two choroid rostral arteries in one giraffe and a unilateral one in two giraffes represented vascular variations. Also, in one specimen the right rostral choroid artery of the brain branched off the middle artery of the brain.

The middle cerebral artery was the widest branch of the central segment in the rostral cerebral artery and, in parallel, in the entire arterial circle of the brain. A double middle cerebral artery was found on the left hand side in two giraffes and bilaterally in one giraffe.

The internal ethmoidal artery most frequently branched off the terminal segment of the rostral cerebral artery and, then, it ramified into numerous arteries located in the olfactory fossa of the ethmoid bone, with which the external ethmoid artery, penetrating via the ethmoid foramen, also communicated.

Bilateral rostral cerebral arteries were anastomosed by the rostral communicating artery, which was located rostrally from the decussation of optic nerves and contributed to the rostral closure of the arterial circle of the brain. Vascular variability included two or three vessels, varying in course and diameter.

The caudal communicating artery, limiting the caudo-lateral segment of the arterial circle of the brain, was characterized by a variable shape and course (Fig. 2).

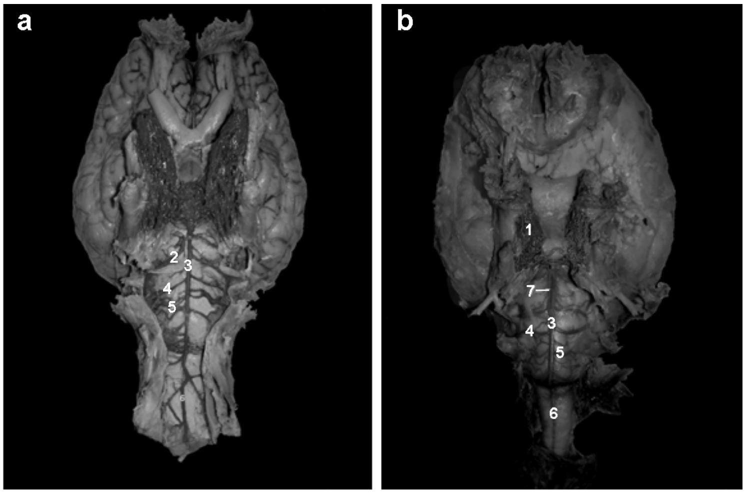

Fig. 1. Ventral view of the cerebral base in the giraffe. — **a**: adult brain, — **b**: fetal brain. 1: rostral epidural rete mirabile, 2: rostral cerebellar artery, 3: basilar artery, 4: caudal cerebellar artery, 5: medulla oblongata branches, 6: ventral spinal artery, 7: "island" shape formation in the basilar artery.

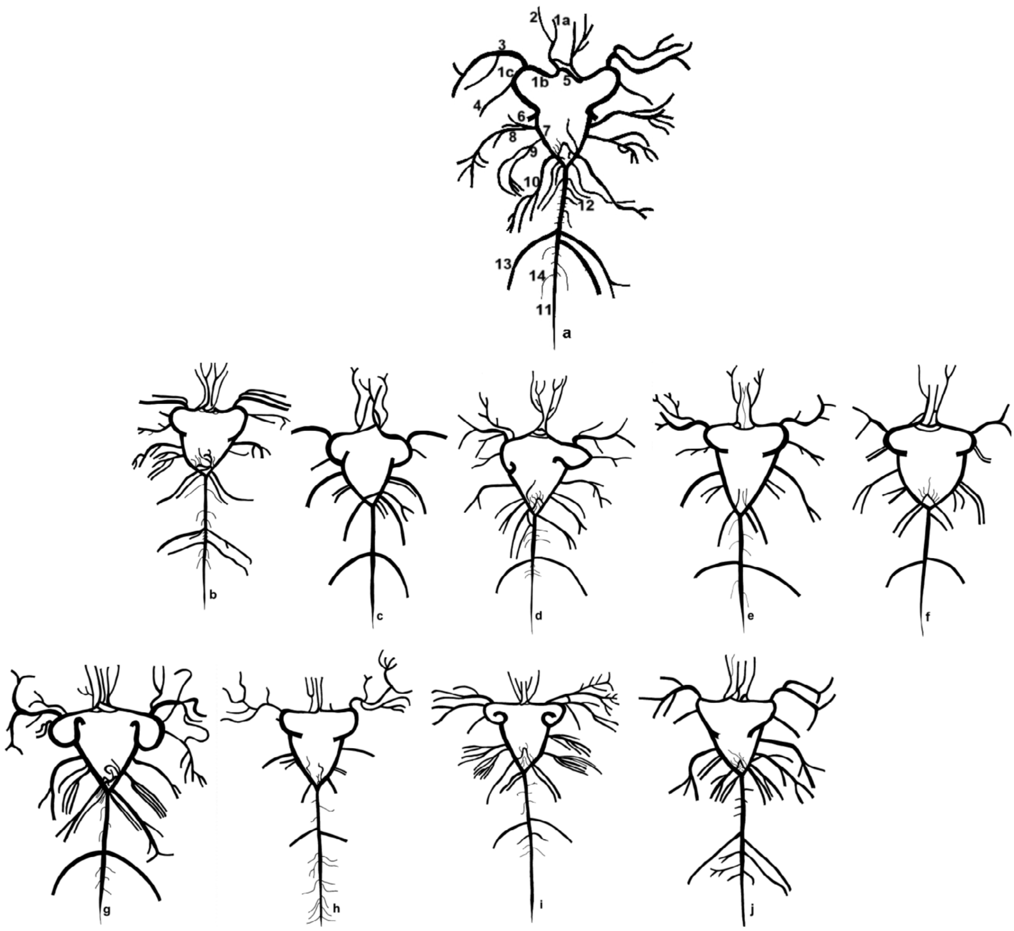

Fig. 2. Variations of the arterial circle of the brain (**a**–**j**). 1: rostral cerebral artery (1a: terminal segment, 1b: middle segment, 1c: first segment), 2: internal ethmoidal artery, 3: middle cerebral artery, 4: rostral choroid artery, 5: rostral communicating artery, 6: internal carotid artery, 7: caudal communicating artery, 8: caudal cerebral artery, 9: caudal choroid artery, 10: rostral cerebellar artery, 11: basilar artery, 12: branches to the pons, 13: caudal cerebellar artery, 14: medulla oblongata branches.

The caudal cerebral artery was the strongest branch of the caudal communicating artery. As a vascular variation, a double caudal artery of the brain was found unilaterally in two animals.

The caudal choroid artery represented another branch of the caudal cerebral artery and in the examined animals a single or double vessels were observed. The method of branching of the caudal choroid artery from the caudal communicating artery showed asymmetry of the branching site. The diameter of the caudal choroid artery in the examined animals varied.

The rostral cerebellar artery branched off the caudal communicating artery near the place of junction of the caudal communicating artery with the basilar artery. It exhibited a considerable asymmetry in the site of branching and in the number of branches. Vascular variations included a double rostral cerebellar artery found bilaterally in four animals and only on the right hand side in one animal. The branching off of the rostral cerebellar artery from the basilar artery was observed in two giraffes. In the vicinity of the site of branching off of the rostral cerebellar artery numerous small vessels were found.

The bilateral caudal communicating arteries were anastomosed by the communicating branch of the arterial circle of the brain, which joined the arterial circle of the brain opposite to the site of branching off of rostral cerebellar arteries.

The basilar artery was located in the ventral median fissure of the medulla oblongata and it anastomosed rostrally with caudal communicating arteries in the vicinity of the anterior margin of the pons. The diameter of the basilar artery varied and its lumen decreased caudally. A vascular island was found in the course of the basilar artery in the fetus (Fig. 1b).

The caudal cerebellar artery and branches to the pons and the medulla oblongata constituted ramifications of the basilar artery.

Among branches to the pons, bilaterally in one and unilaterally in two giraffes, a single, much wider artery could be distinguished, which reached nasal parts of the cerebellum.

The caudal cerebellar artery was the widest ramus of the basilar artery; it branched off the caudal part of the pons and continued to run laterally and dorsally. In all specimens the caudal cerebellar artery showed asymmetry in the method of branching off and a slight asymmetry in diameter. An additional caudal cerebellar artery was found bilaterally in one and unilaterally in two specimens. Caudally, thin and numerous branches to the medulla oblongata branch off the basilar artery starting from the site of ramification of the caudal cerebellar artery. The pattern of ramification to the medulla oblongata was asymmetric.

Discussion

The brain in the giraffe, similarly as in other species, is supplied by vessels branching off the arterial circle of the brain, which forms rami of the terminal segmentation in the internal carotid artery, anastomosed with the basilar artery. The internal carotid artery in the giraffe, similarly as in other ruminants (Godynicki & Frąckowiak 1979, Frąckowiak 2003), undergoes partial obliteration during ontogenesis. A reduction of the intracranial segment of the internal carotid artery results in a situation where blood reaches the brain from the maxillary artery via vessels of the rostral epidural rete mirabile. In the giraffe, rostral branches and the caudal branch supplying blood from the maxillary artery anastomose with the rostral epidural rete mirabile (Godynicki & Frąckowiak 1979, Frąckowiak 2003). Moreover, in the giraffe the condylar artery branching off the occipital artery anastomoses with the rostral epidural rete mirabile (Godynicki & Frąckowiak 1979). The branch of the condylar artery to the rostral epidural rete mirabile found in the giraffe was also observed in animals from the Cervidae family and in the eland from the Bovidae family (Godynicki & Frąckowiak 1979, Frąckowiak 2003). Taking into consideration the data contained in the study by Scott and Janis (1993) it may be assumed that it is another morphological piece of evidence confirming close relation of the two families to the family Giraffidae.

In the giraffe, similarly as in other Artiodactyla (Godynicki & Frąckowiak 1979, Frąckowiak 2003) the internal carotid artery preserves the intracranial segment, which is encircled by dense vessels of the rostral epidural rete mirabile (the intraretal segment), and subsequently it emerges from the rete as a supraretal segment and undergoes terminal segmentation into vessels forming the arterial circle of the brain.

Terminal parts of the intraretal segment of the internal carotid artery are joined by the caudal intercarotid artery.

This artery was described in the cat by Hürlimann (1913), Martinez (1965) and Klein (1980), while in the dog by Habermehl (1973). In species from the order of Perissodactyla the caudal intercarotid artery was described by Frąckowiak and Giejdasz (1998), Jenke (1919), Barone and Schafer (1952–1953), Rösslein (1987), and Nanda and Getty (1975).

Following the study by Simoens *et al.* (1978–1979) and in accordance with Nomina Anatomica Veterinaria (1994), three segments are distinguished in the course of the rostral cerebral artery in the giraffe, including the first, the middle and the terminal segment (Fig. 2).

In some studies the nomenclature concerning the rostral cerebral artery differs from the guidelines contained in Nomina Anatomica Veterinaria (1994).

An original view in this respect was presented by Sisson and Grossman (1953) in the case of cattle, and by Shoshani *et al.* (2006) in the elephant, who denoted the first segment of the rostral cerebral artery as the internal carotid artery. Among the described vascular variations a special case may involve the absence of the first segment of the rostral cerebral artery in humans (Lippert 1969).

Kanan (1970) in the dromedary, Brudnicki (2000) in the goat, Klein (1980) in the domestic cat and Jenke (1919) in the horse, dog, pig and in cattle denoted the terminal segment of the rostral cerebral artery as the artery of the corpus callosum.

In some studies the terminal segment of the rostral cerebral artery was termed the marginal artery (Jabłoński & Wiland 1973, König 1979, Brudnicki 2000).

The rostral communicating artery in the giraffe anastomosed bilaterally with rostral cerebral arteries, contributing to closure of the arterial circle of the brain. A complete absence of the nasal communicating artery in the cat was reported by Kamijyo and Garcia (1975) and Hürlimann (1913), while in the pig, cattle and the horse it was documented by Gillilan (1974).

The rostral choroid artery — the first ramus of the rostral cerebral artery in vascular variations — was formed by two vessels. A similar vascular variation in animals from the Equidae family was described by Frąckowiak and Giejdasz (1998). In the tapir and in the elephant this artery represents a branch of the caudal communicating artery (Frąckowiak & Giejdasz 1998, Shoshani *et al.* 2006).

The middle cerebral artery in vascular variations was formed by two vessels branching off the rostral cerebral artery.

A double middle cerebral artery was observed unilaterally or bilaterally in the horse (Jenke 1919, Rösslein 1987) and in odd-toed ungulates (Frąckowiak & Giejdasz 1998). Similar variation was described in the silver fox (Wiland 1991), in the pig and the wild boar (Wiland & Maliński 1968, Gillilan 1974, Wiland & Brudnicki 1984, Jabłoński *et al.* 1989), in the hare and coypu (Wiland & Brudnicki 1984), in the rabbit (Wiland & Maliński 1968), in the roe deer (Godynicki & Wiland 1971), in the elk deer (Jabłoński *et al.* 1999) and in the European bison (Węgrzyn *et al.* 1983).

The caudal communicating artery joins the internal carotid artery with the basilar artery. In the rat, in the posterio-lateral part of the arterial circle of the brain Brown (1966) and Moffat (1962) distinguished the caudal communicating artery, branching off the internal carotid artery, and the caudal cerebral artery, representing an extension of the basilar artery. In the horse Jenke (1919) described the caudal communicating artery as the caudal communicating branch of the internal carotid artery. Rösslein (1987) denoted this vessel in the horse as the caudal branch of the arterial circle of the brain.

Within vascular variations in the giraffe, the caudal cerebral artery, the first and widest branch of the caudal communicating artery, was found in the form of two arteries and showed asymmetry of the branching sites. Multiple caudal cerebral arteries were also described in the chinchilla (Roskosz *et al.* 1988), in the sheep (Jabłoński & Wiland 1973), in the roe deer and deer (Godynicki & Wiland 1970, 1971), as well as in odd-toed ungulates (Frąckowiak & Giejdasz 1998).

Nomenclature concerning the caudal communicating artery of the brain also varies. In the horse Jenke (1919) called this vessel the caudal communicating branch of the internal carotid artery, while Rösslein (1987) reported it as the caudal branch of the arterial circle of the brain.

The caudal choroid artery is another branch of the caudal communicating artery, in which reported vascular variations include the presence of two such arteries and asymmetry of the branching site. Similar vascular variations in the goat were described by Brudnicki (2000).

The rostral cerebellar artery is represented by one or two vessels, which branch off the caudal communicating artery and — as a vascular variation — off the basilar artery.

The even caudal cerebellar artery is the main branch of the basilar artery and the vascular variations of it include the uni- or bilateral presence of a double caudal cerebellar artery.

Double caudal cerebellar arteries were described in Equidae (Frąckowiak & Giejdasz 1998), in Felidae (Frąckowiak & Godynicki 2003), in the rat (Jabłoński 1975), in the guinea pig (Brenner 1977), in the Canadian beaver (Pilleri 1983), in the horse (Rösslein 1987) and in other odd-toed ungulates (Frąckowiak & Giejdasz 1998).

The diameter of the basilar artery in the giraffe, similarly as in other even-toed ungulates, varies and decreases caudally. Baldwin and Bell (1963a, 1963b, 1963c) in their experiments on the blood flow in the sheep and cattle showed variation in the diameter of the basilar artery.

Conclusions

1. In the giraffe the arterial circle of the brain is supplied mainly by the maxillary artery via the rostral epidural rete mirabile.
2. In the giraffe, similarly as in Cervidae and Bovidae, the rostral epidural rete mirabile is anastomosed with the ramus branching off the condylar artery.
3. In the giraffe arteries branching off the arterial circle of the brain exhibit vascular variations and asymmetry.

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