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Analysis of morphological variation of the internal ophthalmic artery in the chinchilla (*Chinchilla laniger*, Molina)

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ABSTRACT: The aim of this investigation was the analysis of the variability within the internal and external ophthalmic artery in the chinchilla (*Chinchilla laniger*, Molina). The head vasculature of 65 individuals was analysed, with particular emphasis on the internal ophthalmic artery originating from the central and rostral part of the cerebral arterial circle. Head blood vessels were filled with acrylic latex for vascular corrosion casting. The results showed ten variants of blood supply for the orbit, with a predominance of the first variant (66.1%) = bilateral presence of the external ophthalmic artery originating from the maxillary artery. Other variants differed in symmetry and asymmetry, sites of origination and the coexistence of both internal and external arteries. Vascularisation of the brain in chinchillas originates mainly from the vertebra-basilar system. The observed variability seems to confirm the role of the basilar artery in the arterial blood supply of the brain in this species.

Keywords: variability; head arterial system; rodents

The arterial system in the head of animals, including mammals, has long been of interest for anatomists, from the early works by Hyrtl (1854), Tandler (1899), Hafferl (1938) to more recent papers by Bugge (1971a, 1971b, 1972, 1978, 1985) and Frackowiak (2003). The brain base arteries have been described in many reports on various animal species: giraffe (Frackowiak and Jakubowski 2008), Felidae (Frackowiak and Godynicki 2003), European beaver (Frackowiak and Smielowski 1998), fallow deer (Godynicki 1972), deer (Godynicki and Wiland 1970), monkey, dog, goat, sheep and rabbit (Kapoor et al. 2003), Mongolian gerbil (Kuchinka et al. 2008), Egyptian spiny mouse (Szczurkowski et al. 2007), red squirrel (Aydin 2008) and species of *Bovini* Tribe (Zdun et al. 2013). The arterial blood supply in chinchillas (in various aspects) has been described by Gielecki et al. (1996), Jablonski and Brudnicki (1984), Roskosz et al. (1988) and Araujo and Campos (2005).

Internal ophthalmic arteries have been described in various animals, such as the ox (Steven 1964), dog (Evans and Lahunta 1993), horse (Ellenberger and Baum 1912), cat (Davis and Story 1943) and rabbit Ruskell (1962). Circulatory variations of the ophthalmic artery in humans were described by Grossman et al. (1982). Sade et al. (2004) reported that the ophthalmic artery originates from the basilar artery. Bervini and Assaad (2014) described the ophthalmic artery arising from the A-1 segment of the anterior cerebral artery.

Chinchilidae, similar to Hystricidae, Cavidae, Hydrochoeriadae, Dasproctidae and Myocactorridae have an obliterated extracranial part of the internal carotid artery (Frackowiak 2003). The characteristic feature of head vasculature in rodents is its variation in ramification, origins of vessels and connections between them. In chinchillas, a reduction of the internal carotid artery leads to a supply of the cerebral arterial circle through the vertebrobasilar system, which corresponds to a type 3 vascularisation as proposed by De Vriese (1905) in vertebrates, where encephalic irrigation is almost exclusively carried out by the vertebrobasilar system. However, literature on the vascular system of the head of the chinchilla lacks comprehensive data on the participation of internal ophthalmic arteries in the structure of the cerebral

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arterial circle. Therefore, the diversity in the arrangement of head arteries in rodents was the main premise of this study which focused on the vascular area belonging to the maxillary and basilar arteries in the chinchilla.

MATERIAL AND METHODS

The research involved 65 (n = 65) adult chinchillas (*Chinchilla laniger*) of both sexes (23 males and 42 females) weighing 550–700 g. The animals were gradually collected over six months from fur farms. After slaughter, the chest was immediately opened. Using a corneal scissor, a small incision was made in the posterior end of the left ventricle. The right cardiac auricle was then transected. A perfusion needle was passed through the cut and the left ventricle into the ascending aorta. The arterial system was washed with cold 0.9% saline solution mixed with 5000 IU heparin (Heparinum, Polfa, Warszawa, Poland) and then gently filled with red-coloured (Pigment-Mix, Inchem, Lodz, Poland) acrylic latex (LBS 3060, SYNTHOS, Dwory-Oswiecim, Poland). Some of the material was fixed in 7% formaldehyde solution. After coagulation of the latex, the material was placed in a 5% solution of hydrochloric acid for the decalcification of the skull bones for seven days.

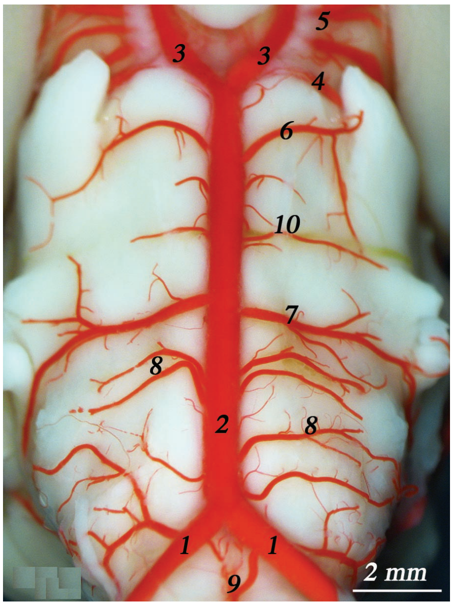

Figure 1. Vertebrobasilar system. 1 = vertebral arteries, 2 = basilar artery, 3 = terminal branches of basilar artery, 4 = rostral cerebellar artery, 5 = caudal cerebral artery, 6 = trigeminal artery, 7 = caudal cerebellar artery, 8 = *rami ad medulla oblongata*, 9 = ventral spinal artery, 10 = *rami ad pontem*

The external carotid arteries and their ramifications were precisely dissected, with particular focus on the external ophthalmic arteries, cerebral arterial circle and internal ophthalmic arteries. From the second part of the material, a vascular corrosion cast was made. The material was placed in a 20% KOH solution at 30 °C until complete maceration. The experiment was performed using a stereoscopic microscope (SMZ 800, Nikon,Tokyo, Japan). Photographic documentation was performed using a Nikon Digital Sight DS-L3 (Tokyo, Japan). In this study terminology consistent with the veterinary anatomical nomenclature (ICVGAN, 2005) was used. This study was approved by the First Local Ethical Committee on Animal Testing – Krakow (3/2011). The terminology used to name the arteries followed that of the Nomina Anatomica Veterinaria (2012).

RESULTS

In the chinchilla the main vessel, which supplies the brain with blood was the basilar artery originating from two vertebral arteries. This was found in 64 out of 65 examined cases (Figure 1). In one case, the basilar artery originated from a vessel which had to be regarded as the right internal carotid artery (Figure 2).

The main vessel supplying the eyeball and the orbital structure was the external ophthalmic artery,

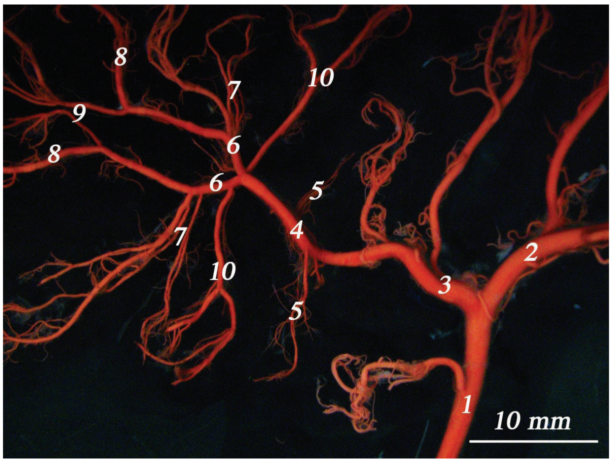

Figure 2. Basilar artery originating from the left internal carotid artery (corrosion cast). 1 = common carotid artery, 2 = external carotid artery, 3 = internal carotid artery, 4 = basilar artery, 5 = caudal cerebellar arteries, 6 = terminal branches of basilar artery, 7 = caudal cerebral arteries, 8 = medial cerebral arteries, 9 = rostral cerebral arteries, 10 = rostral cerebellar arteries

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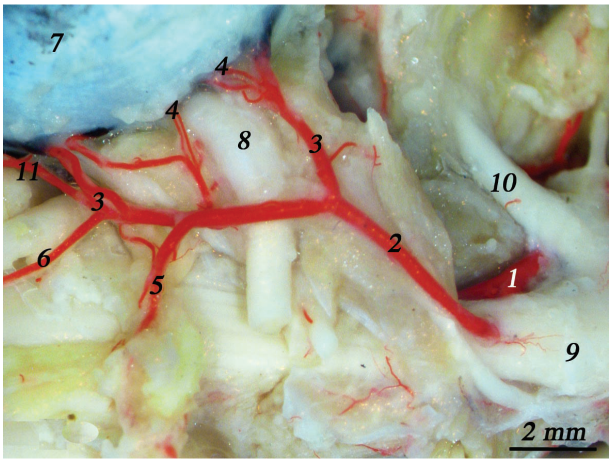

Figure 3. External ophthalmic artery originating from the maxillary artery – right side, dorsal view, Variant A. 1 = maxillary artery, 2 = external ophthalmic artery, 3 = long posterior ciliary arteries, 4 = short posterior ciliary arteries, 5 = muscle branches, 6 = external ethmoidal artery, 7 = eyeball, 8 = optic nerve (cut), 9 = maxillary nerve (V2), 10 = mandibular nerve (V3), 11 = arterial branch to Harderian gland

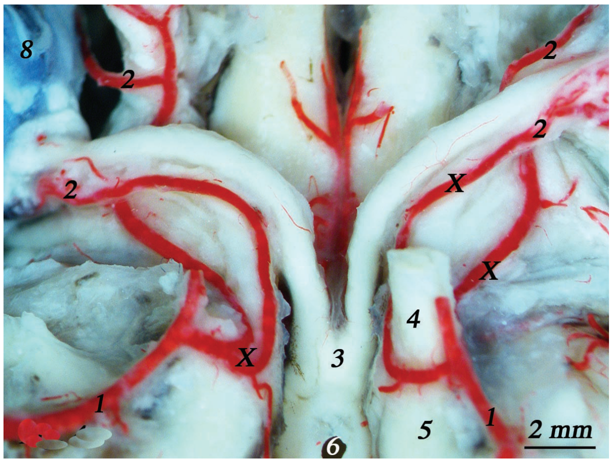

Figure 4. Double external ophthalmic arteries originating from the right and the left maxillary arteries – ventral view, Variant J. 1 = maxillary artery, 2 = long posterior ciliary artery, 3 = optic chiasm and optic nerves, 4 = V2 – maxillary nerve, 5 = trigeminal nerve, 6 = pituitary stalk (cut), 7 = eyeball, X = double external ophthalmic arteries

present – in different configurations – in 60 cases (92.3%). The artery was a branch of the maxillary artery running, medially crossed, towards the top or through the maxillary nerve. It then entered the orbit through the orbital fissure. In the orbit, the ophthalmic artery divided into many vessels, including the supraorbital branch, external ethmoidal artery, long posterior ciliary arteries – lateral and medial, a branch supplying the Harderian gland, muscular branches and small vessels of the orbital fat-pad (Figure 3).

In one case, the double ophthalmic arteries ran bilaterally from the left and right maxillary arteries. The left maxillary artery divided into two separate external ophthalmic arteries. On the right side, there were also two ophthalmic arteries, which formed a short common trunk. Without anastomosis between each other and with the surrounding vessels, these twin vessels reached the posterior surface of the eyeballs, each giving an origin to a long posterior ciliary artery (lateral and medial, respectively), small short posterior ciliary arteries and other orbital vessels (Figure 4).

The external ophthalmic artery, as a single vessel of the eyeball and the orbit, occurred bilaterally in 44 cases (67.6%), bilaterally together with internal ophthalmic arteries in three cases (4.6%) and bilaterally with asymmetric internal ophthalmic arteries in nine cases (13.8%). In one case double internal ophthalmic arteries were observed (1.6%). In six cases (6.9%) the presence of external ophthalmic arteries was not observed at all.

In the chinchilla the internal ophthalmic artery was an inconstant vessel, originating from terminal branches of the basilar artery (Figure 10, Table 1). In five cases (7.7%) the eyeball was supplied only by rostral internal ophthalmic arteries. In one case (1.5%) double internal ophthalmic arteries were observed (rostral and caudal) originating bilaterally from terminal branches of the basilar artery. In one case (1.5%) similar double vessels were found only on the right side. In the case of occurrence of double internal ophthalmic arteries the eyeball and content of the eye socket were supplied without participation of external ophthalmic arteries (Figures 6, 10). In the direction of the orbit, rostral and caudal internal ophthalmic arteries always accompanied the inferior surface of the optic nerve and entered the orbit through the optic nerve canal. In the orbit, the ophthalmic arteries divided into the long posterior ciliary arteries (lateral and medial), short posterior ciliary arteries, supraorbital artery and external ethmoidal artery. Further branches reached the Harderian gland and parts of the external muscles of the eyeball and orbital fat-pad (Figure 5).

When the eyeball was vascularised by a single ophthalmic artery (external or internal), it divided

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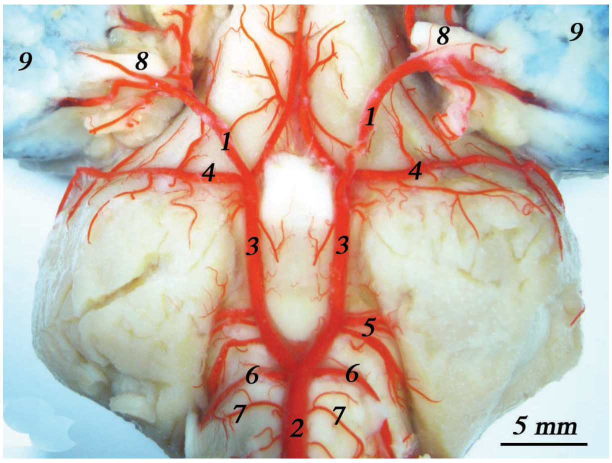

Figure 5. Ventral view of the brain base arteries with symmetrical internal ophthalmic arteries, variant B. 1 = internal ophthalmic arteries, 2 = basilar artery, 3 = terminal branches of the basilar artery, 4 = medial cerebral artery, 5 = caudal cerebral artery, 6 = rostral cerebellar artery, 7 = trigeminal artery, 8 = optic nerves (cut), 9 = eyeball

into the long posterior ciliary arteries (lateral and medial). When the eyeball was supplied with blood by both internal and external ophthalmic arteries, each of these vessels individually gave origin to its own long posterior ciliary artery (lateral and medial). The external ophthalmic artery gave rise to the long medial long ciliary artery and the internal ophthalmic artery gave rise to the long posterior lateral ciliary artery (Figures 7, 8).

Therefore, the orbit was supplied with blood in three ways:

– only by the external ophthalmic arteries
– only by the internal ophthalmic arteries

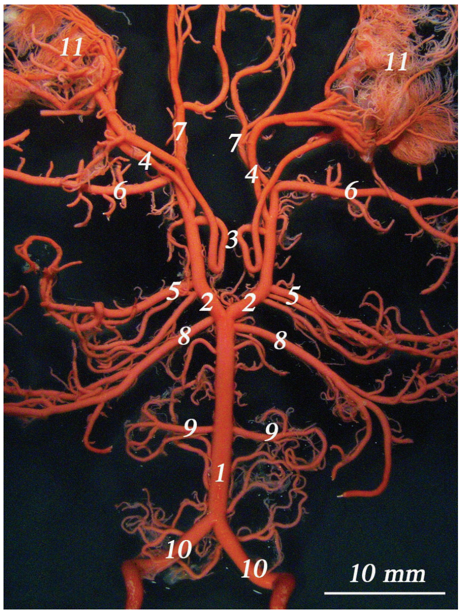

Figure 6. Rostral and caudal internal ophthalmic arteries symmetrically arise from the terminal branches of the basilar artery. Ventral view, (corrosion cast), variant G. 1 = basilar artery, 2 = terminal branches of the basilar artery, 3 = caudal internal ophthalmic arteries, 4 = rostral internal ophthalmic arteries, 5 = caudal cerebral arteries, 6 = medial cerebral arteries, 7 = rostral cerebral arteries, 8 = rostral cerebellar arteries, 9 = caudal cerebellar arteries, 10 = vertebral arteries, 11 = eyeball vessels

– jointly by two vessels (in various configurations)

In addition, the symmetry and asymmetry of the ophthalmic arteries resulted in 10 variants of blood supply of the eyeball in the chinchillas (Figure 10. Table 1):

Table 1. Variants of blood supply to the eyeball in the chinchilla

Variants	EOA^L	EOA^R	$IOAR^L$	$IOAR^R$	$IOAC^L$	$IOAC^R$	Number	%
I	+	+	–	–	–	–	43	66.1
II	–	–	+	+	–	–	5	7.7
III	+	+	–	–	+	–	4	6.1
IV	+	+	+	+	–	–	3	4.6
V	+	+	+	–	–	–	4	6.1
VI	–	–	+	+	+	+	2	3.0
VII	+	–	+	+	–	–	1	1.5
VIII	+	–	+	+	–	–	1	1.5
IX	+	+	–	+	–	–	1	1.5
X	++	++	–	–	–	–	1	1.5

EOA = external ophthalmic artery, IOAR = rostral internal ophthalmic artery, IOAC = caudal internal ophthalmic artery
^{L}left, ^{R}right

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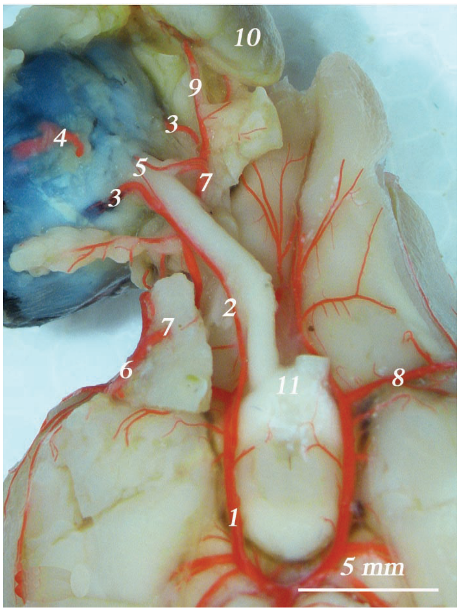

Figure 7. Internal ophthalmic artery – right side. The left internal ophthalmic artery and the eyeball were removed. Dorsal view, variant E. 1 = terminal branches of the basilar artery, 2 = internal ophthalmic artery, 3 = long posterior ciliary arteries, 4 = vorticose vein, 5 = short posterior ciliary arteries, 6 = maxillary artery, 7 = external ophthalmic artery, 8 = middle cerebral artery, 9 = branch of Harderian gland, 10 = Harderian gland, 11 = optic chiasm and right optic nerve

Variant **A** was found in 44 cases (67.6%); external ophthalmic arteries were the only vessels supplying the orbital structures. They were individual vessels running bilaterally from maxillary arteries.

Variant **B** was observed in five cases (7.7%); only isolated rostral ophthalmic arteries occurred bilaterally, originating from the terminal branches of the basilar artery at the same level, just before the origin of the middle cerebral arteries.

Variant **C** was observed in four cases (6.1%); the external ophthalmic artery was detected on the right side. On the left side were the external ophthalmic artery and the internal "caudal" ophthalmic artery originating from the terminal branch of the basilar artery at the level of the hypophyseal artery.

Variant **D** occurred in three cases (4.6%); external ophthalmic arteries on both sides and rostral internal ophthalmic arteries were observed.

Variant **E** was present in four cases (6.1%); the rostral internal ophthalmic artery and the external ophthalmic artery were on the right. On the left was the external ophthalmic artery.

Variant **F** was observed in two cases (3.0%); on the left side was the external rostral ophthalmic artery. On the right side was the internal ophthalmic artery.

Variant **G** was observed in a single case (1.5%) with bilateral presence of double external ophthalmic arteries (rostral and caudal). The internal "rostral" ophthalmic arteries originated from terminal branches of the basilar artery just before the medial cerebral arteries. The internal "caudal" ophthalmic arteries originated from the terminal branches of the basilar artery at the level of the hypophyseal artery.

Variant **H** was observed in a single case (1.5%) on the right side – two internal ophthalmic arteries (rostral and caudal), on the left side – the rostral internal ophthalmic artery and external ophthalmic artery.

Variant **I** was observed in a single case (1.5%); on the left the rostral internal ophthalmic artery and external ophthalmic artery were present, with an external ophthalmic artery on the right.

Variant **J** was observed in a single case; twin external ophthalmic arteries originated bilaterally from maxillary arteries.

In variant **E** in one case there was an incomplete cerebral arterial circle without an anterior communicating artery and anterior cerebral artery on the left side (Figure 9). There was no anastomisation between external and internal ophthalmic arteries and the maxillary artery.

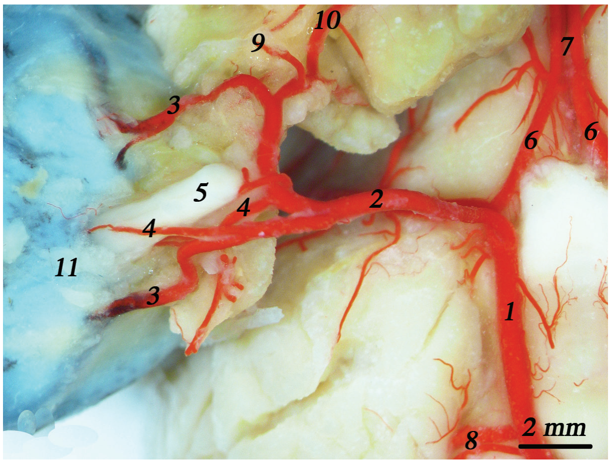

Figure 8. Division of a single internal ophthalmic artery. 1 = terminal branches of the basilar artery, 2 = internal ophthalmic artery, 3 = long posterior ciliary arteries, 4 = short posterior ciliary arteries, 5 = optic nerve (cut), 6 = rostral cerebral artery, 7 = internal ethmoidal artery, 8 = posterior cerebral artery, 9 = external ethmoidal artery, 10 = branch to Harderian gland, 11 = eyeball

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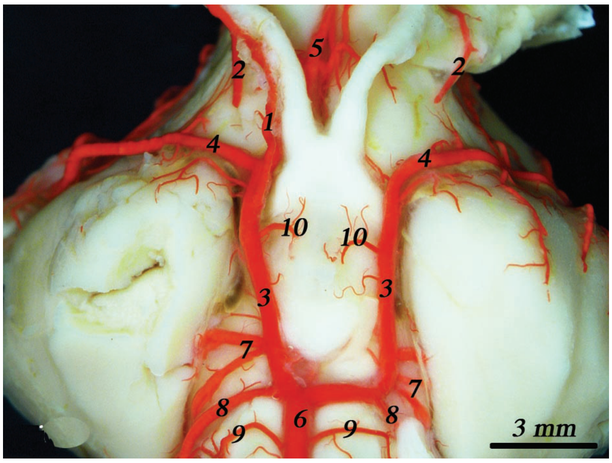

Figure 9. Asymmetrical and incomplete cerebral arterial circle without rostral cerebral artery on the left side, variant E. 1 = internal ophthalmic artery, 2 = external ophthalmic arteries, 3 = terminal branches of basilar artery, 4 = medial cerebral artery, 5 = rostral cerebral artery, 6 = basilar artery, 7 = caudal cerebral artery, 8 = rostral cerebellar artery, 9 = trigeminal arteries, 10 = hypophyseal arteries

In one case of the variant **A** an incomplete and asymmetrically cerebral arterial circle without an anterior communicating artery and anterior cerebral artery on the left side was observed. No connections between the internal and external ophthalmic arteries were observed. Analogically, connections between the internal ophthalmic artery and the maxillary artery were not observed.

DISCUSSION

The presence of internal ophthalmic arteries has been reported in many species of animals. In the ox (*Bos taurus*) (Steven 1964) and Japanese deer (*Cervus nippon*), (Ninomiya and Masui 1999), these vessels originate from the anterior part of the *rete mirabile* of the carotid artery and accompany the intracranial optic nerve. In yak (*Bos grunnines*) and sheep (*Ovis aries*), the ophthalmic artery originates from the *rete chiasmaticum* = part of the rostral epidural rete mirabile (Simoens and Ghoshal 1981; Shao et al. 2007). In the rabbit (*Oryctolagus cuniculus*), Davis (1929) defined the ophthalmic artery as a very thin internal branch of the carotid artery. Brudnicki et al. (2012) and De Souza and Campos (2013) described the internal ophthalmic artery in the wild rabbit (*Oryctolagus cuniculus*) to originate

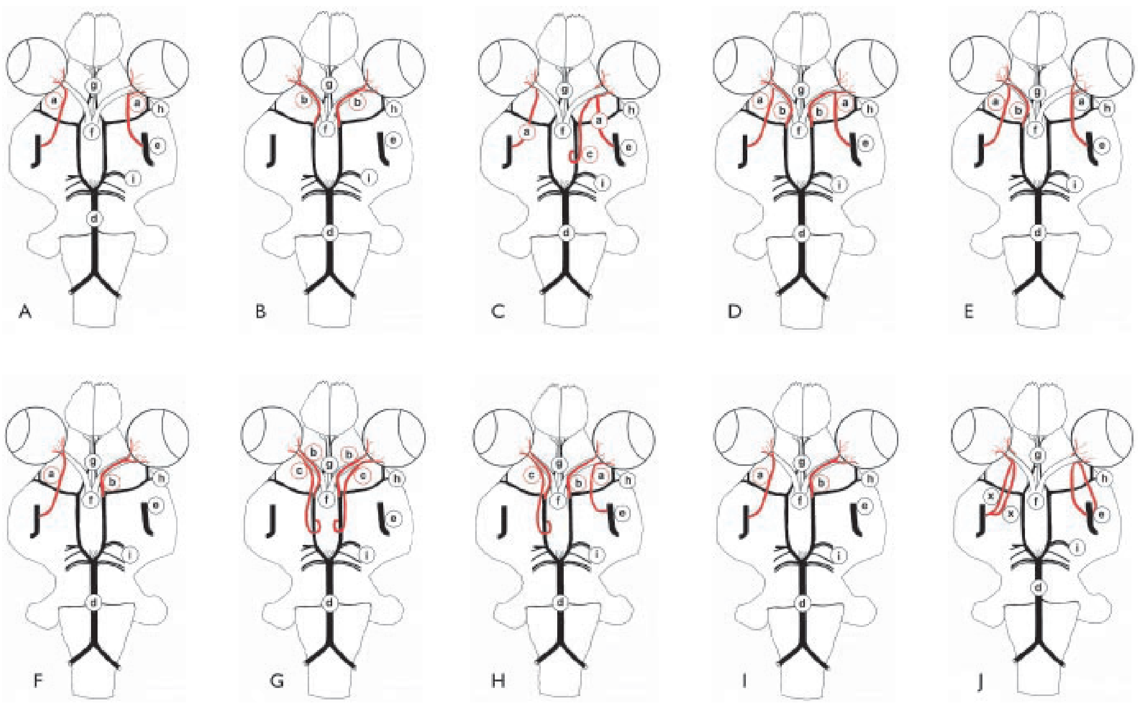

Figure 10. Diagram of variability of the external and internal ophthalmic arteries in the chinchilla. a = external ophthalmic artery, b = rostral internal ophthalmic artery, c = caudal internal ophthalmic artery, d = basilar artery, e = maxillary artery, f = optic nerve, g = internal ethmoidal arteries, h = medial cerebral arteries, I = caudal cerebral arteries, x = double external ophthalmic arteries, A to J see explanations in text of paper

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from the vessels of the cerebral arterial circle at the height of the rostral choroidal artery and as the lateral branches of rostral and caudal branches of the internal carotid artery. In the lesser mole rat (*Spalax leucodon*), the internal ophthalmic artery is a branch of the internal carotid artery (Aydin et al. 2008). In the European ground squirrel, it is a branch of the common carotid artery (Aydin et al. 2009). In the domestic goat (*Capra hircus*) (Brudnicki 2000), and German shepherd (Kurtul et al. 2002), pampas fox (*Lycalopex gymnocercus*) (Depedrini and Campos 2003), fox (*Vulpes vulpes*) (Ozudogru et al. 2012) and capybara (*Hydrochoerus hydrochaeri*) (Reckziegel et al. 2001), the internal ophthalmic artery originates from the rostral or middle part of the cerebral arterial circle. In the Mongolian gerbil, Kunzel (1985) observed delicate and long internal ophthalmic arteries, extending asymmetrically from the branches of the basilar artery near the caudal cerebral arteries. Ocal and Ozer (1992) described the arterial vasculature of the guinea pig brain to originate mainly from internal ophthalmic arteries. The internal carotid arteries were extremely thin. Shively and Stump (1974) emphasised the small diameter of the internal carotid arteries. Nilges (1944) stated that in guinea pigs the internal carotid artery plays no part in the formation of the circle of Willis. This vessel enters the cranial cavity and immediately leaves it as the ophthalmic artery. According to Majewska-Michalska (1994), only the vertebrobasilar system supplies blood to the arterial circle in the guinea pig. Variation in the head vasculature, characteristic especially for rodents, is confirmed also in chinchillas. As a result of obliteration of the common carotid artery, probably the only and also sufficient source of vascularity of the brain is the basilar artery originating from both vertebral arteries. According to Gielecki et al. (1996) the brain of the chinchilla may be vascularised only by the basilar artery, thanks to geometric parameters and correlation between the parameters of the basilar artery, and the total volume of the cerebral arterial circle. The observed single case of the basilar artery originating from the right internal carotid artery was also reported by Araujo and Campos (2005).

In chinchillas, the external ophthalmic artery is a branch of the maxillary artery, which according to Bugge (1985) is an anastomosis connecting the distal part of the external carotid artery with the mandibular branch of the stapedial artery. The internal ophthalmic artery is an unstable vessel. If present, it goes symmetrically or asymmetrically from the terminal or middle part of the terminal branch of the basilar branch. This is confirmed by the observations of Araujo and Campos (2005).

The external ophthalmic artery may accompany the internal ophthalmic artery. When the internal ophthalmic artery occurs on its own (sometimes as a double artery), it is then the only vessel supplying the eyeball and orbit. The diameter of these vessels is significant and is 0.8 ± of parent vessels. In many descriptions the internal ophthalmic artery is defined as a weak vessel (De La Torre at al. 1962; Steven 1964; Gillilan 1976; Majewska-Michalska 1994; Depedrini and Campos 2003; Frackowiak 2003), while it is sometimes described as a persistent vessel (Steven 1964; Wang 2002). Frackowiak (2003) reported that, for example in Chinchillidae, the basilar artery that vascularises the brain is assisted by the maxillary artery via the external ophthalmic artery connected to the cerebral arterial circle via the internal ophthalmic artery.

In the present study, there was no connection observed between the internal ophthalmic artery and the maxillary artery and external ophthalmic artery. There was also no reverse flow of blood through the internal ophthalmic arteries. The lack of anastomoses between the internal ophthalmic artery and the maxillary artery in the chinchilla confirms the observations of Araujo and Campos (2005). The described variability, symmetry and asymmetry of ophthalmic arteries in the chinchilla is a confirmation of the biodiversity of mammals in general. In rodents, this diversity may be regarded as structural variation, most likely caused by both environmental and genetic factors.

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