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The internal carotid artery of the domestic pig and Eurasian wild boar in ontogenesis

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SUMMARY

Available publications and textbooks provide conflicting information regarding the nomenclature of the extracranial part of the internal carotid artery (*arteria carotis interna*) and its course to the rostral epidural rete mirabile (*rete mirabile epidurale rostrale*) in the domestic pig. The aim of the study was to determine the direct course of the internal carotid artery and the time of obliteration in the domestic pig and Eurasian wild boar. The study was conducted on 80 domestic pigs and 50 Eurasian wild boars of both sexes. Two methods were used in the study. The first method consisted of passing coloured liquid latex LBS 3060 into both common carotid arteries, leaving it to set in 5% formalin solution for 2 weeks, and then preparing the blood vessels manually using surgical instruments during dissection. In the second method, both common carotid arteries were filled with a solution of DURACRYL® PLUS chemically cured acrylic resin and macerated enzymatically for about a month. The internal carotid artery was present in all foetuses and pigs from birth to 7 months of age. The internal carotid artery bends dorsally on the bulla tympanica and passes through the petro-tympanic fissure. It joins the rostral epidural rete mirabile laterally. At 9 months of age the artery is fully obliterated. Knowledge of this region is not only important in descriptive and comparative anatomy, as the domestic pig is a laboratory animal, in some ways very similar to humans, which makes it valuable as an experimental model. Despite minor differences in the vascular system, the domestic pig is used as a model in research on the human vascular system.

KEY WORDS: anatomy, domestic pig, Eurasian wild boar, vascularization of the head, vessels

INTRODUCTION

In scholarly works, information concerning the presence of the internal carotid artery (*arteria carotis interna*) in the arterial system of the head of the domestic pig and the nomenclature of the vessel supplying the rostral epidural rete mirabile (*rete mirabele epidurale rostrale*) seem to be

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imprecise or even contradictory. In the standardized nomenclature of *Nomina Anatomica Veterinaria*, the vessel forming the rostral epidural rete mirabile is referred to as the internal carotid artery, whereas its thin branch having its course in the tympanic cavity (bulla tympanica) is referred to as a branch to the rostral epidural rete mirabile (*ramus ad rete mirabele epidurale rostrale*). According to the authors of some studies, the main vessel from which the rostral epidural rete mirabile is formed is the ascending pharyngeal artery (*arteria pharyngea ascendens*), which is equivalent to the internal carotid artery in humans (Mc Grath, 1997; Losif et al., 2016). Other researchers, in addition to the ascending pharyngeal artery, distinguish the internal carotid artery as a vessel running through the tympanic cavity, which obliterates shortly after birth (Tandler, 1906; Lehman, 1905a,b; Von Hoffman 1914; Llorca, 1933; Daniel et al., 1953; Uehara et al., 1978; Godynicki and Frąckowiak, 1979, Wible, 1984; Reinert et al., 2005). Other works, analogously to the nomenclature of *Nomina Anatomici Veterinaria* (2017), consider the internal carotid artery to be a thick vessel forming the rostral epidural rete mirabile, but do not include the segment running through the tympanic part of the temporal bone (Schummer et al., 1981; Oliveira and Campos, 2004; Lima et al., 2005; König et al., 2007; Tsandev, 2020; Krysiak and Świeżyński, 2021). None of the cited works specify the exact time of obliteration of the extracranial segment; this period is a subject of conjecture and estimated at several weeks after birth, as in cats or ruminants (Zdun et al., 2013; Ziemak et al., 2021). These facts inspired our attempt to clarify this contradictory information.

The aim of the study is to determine the exact course of the internal carotid artery, based on analogy to its course in other mammals, to describe its role in the system of cerebral arterial vascularization of the domestic pig and Eurasian wild boar, and to determine the time of its obliteration.

MATERIALS AND METHODS

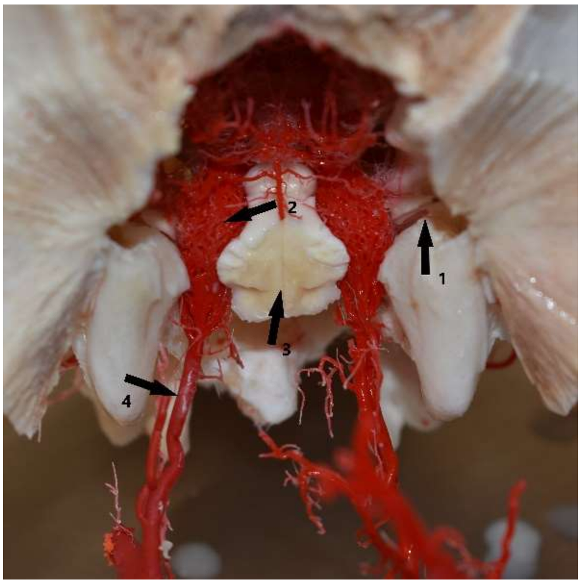
The study was conducted on 80 domestic pigs and 50 Eurasian wild boars of both sexes. The material comprised 20 domestic pig foetuses with CRL of 120-150 mm, 40 domestic pigs from birth (115th day of gestation) to 21 days of age, 20 domestic pigs aged 4 to 10 months, 30 Eurasian wild boar foetuses with CRL 110-130 mm, and 20 adult Eurasian wild boar. The material was obtained from pig farms and hunting. Ethical review and approval were waived for this study because the experimental work was conducted on cadavers. According to the law of 15 January 2015 on the protection of animals used for scientific or educational purposes, procedures involving cadavers do not require the approval of the local ethics committee.

The specimens were prepared using two methods, with each specimen randomly assigned to one of the methods. Ninety specimens were prepared by injecting a coloured solution of DURACRYL® PLUS chemically cured acrylic resin (SpofaDental, Jičín) into the bilateral common carotid arteries. After a short time needed for the resin to harden (15-20 minutes), the soft tissues were enzymatically macerated with Persil powder (Henkel, Düsseldorf) at 42°C for about one month. In this manner corrosion casts of vessels on the bone scaffold were obtained. The second method, used for 40 specimens, consisted in introducing coloured liquid LBS 3060 latex into the bilateral common carotid arteries. After curing in 5% formalin solution, the blood vessels were prepared manually using surgical instruments. In this way, blood vessels on the animal's soft tissues were obtained. The names of the anatomical structures were standardized according to *Nomina Anatomica Veterinaria* (2017).

RESULTS

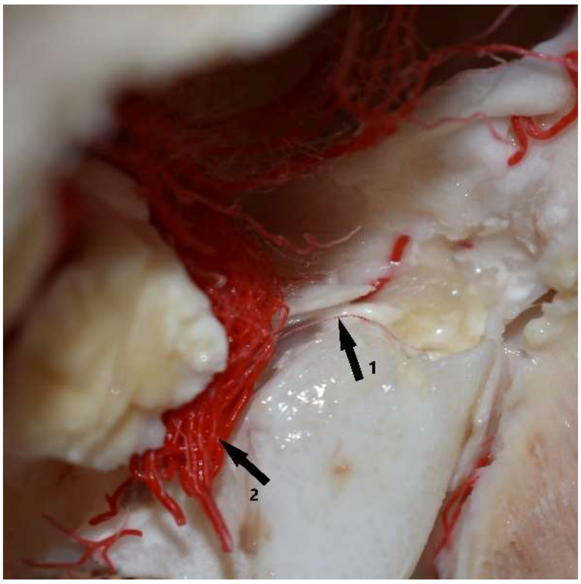
Two segments of the animals' internal carotid artery were distinguished on the basis of its course: the extracranial segment passing through the tympanic cavity and the intracranial segment (Phot. 1 and 2) located in the cranial cavity. The extracranial segment of the internal carotid artery, sharing a common trunk with the condylar artery (*arteria condylaris*) and occipital artery (*arteria occipitalis*), branches off from the common carotid artery (*arteria carotis communis*) and enters the cranial cavity through the petrotympanic fissure (*fissura petrotympanica*). It then arcs through the centre of the tympanic cavity before passing over the surface of the promontory (*promontorium*). It leaves the tympanic cavity on its medial side and, crossing the border of the Eustachian tube, joins the latero-inferior part of the rostral epidural rete mirabile just before entering the foramen lacerum. However, due to its very small diameter it does change the shape of this rete, and thus plays an insignificant role in supplying the brain with arterial blood. The segment of the vessel that continues the course of the arterial trunk and proceeds rostrally past the internal carotid artery is a thick branch to the rostral epidural rete mirabile (Phot. 1), which runs towards the upper-lateral surface of the pharynx, where it bends dorsally to become the main vessel forming the rostral epidural rete mirabile. The intracranial segment of the internal carotid artery, after leaving the rostral epidural rete mirabile, splits terminally into the rostral cerebral arteries (*arteriae cerebri rostralis*) and the caudal communicating arteries (*arteriae communicans caudales*), the main components of the cerebral arterial circle (*circulus arteriosus cerebri*).

Obliteration of the extracranial segment of the internal carotid artery was observed in the domestic pig and the Eurasian wild boar (Phot. 3). The initial stage of obliteration was observed as late as 8 months of age, with atrophy of the initial segment located on the posteromedial surface of the tympanic bulla. The next stage is obliteration of the segment located inside the tympanic cavity, occurring between 8 and 9 months of age. Complete atresia of the extracranial segment of the internal carotid artery, i.e. its last segment joining the rostral epidural rete mirabile, takes place at 9 months of age. The internal carotid artery was not present in any individual at 10 months of age or later.



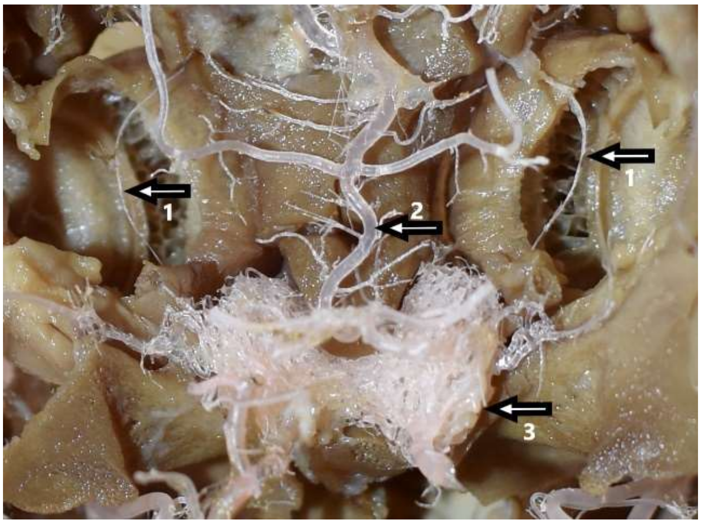
1 – Internal carotid artery, 2 – Rostral epidural rete mirabile, 3 – Sphenoid bone, 4 – Branch to the rostral epidural rete mirabile

Phot. 1. Rostral epidural rete mirabile of domestic pig (caudal view)



1 – Internal carotid artery, 2 – Rostral epidural rete mirabile

Phot. 2. Atrophy of internal carotid artery in domestic pig (caudal view)



1 – Internal carotid artery, 2 – Basilar artery, 3 – Rostral epidural rete mirabile

Phot. 3. Cranial base of Eurasian wild boar foetus (dorsal view)

DISCUSSION

The internal carotid artery contributes to the formation of the cerebral arterial circle, and thus is the main vessel supplying the brain with arterial blood in equines (Jenke, 1919), in which it often becomes a problem associated with gutteral pouch mycosis (Hayah, 2012; Khairuddin et al., 2015). The internal carotid artery is also the main vascular supply for the brain in most carnivores (Matthew, 1909; Nickel and Shwarz, 1963; Bugge, 1978; Frąckowiak 2003). It is present and plays an equally important role in humans as well, and there have been numerous classifications of its course and attempts to standardize its individual segments according to the part of the head through which it passes (Bonasia et al., 2020). The most recent classification seems to be based on 6 segments, i.e. the cochlear segment, petrous segment, gasserian segment, sellar segment, sphenoid segment, and ring segment (Abdulrauf et al., 2016). Brudnicki et al. (2012, 2015) also demonstrated the primary role of this artery in blood supply to the brain via the cerebral arterial circle in lagomorphs. The presence of the internal carotid artery was demonstrated in the European ground squirrel and the red squirrel, but it did not contribute to the arterial supply to the brain, which was compensated for by the basilar artery system (Aydin, 2008; Aydin et al., 2009). Rodents are another order of animals in which the internal carotid artery is one of the main sources of blood to the brain, acquiring a direct connection to the basilar arteries of the brain (Frąckowiak, 2003; Esteves et al., 2013; da Silva Costa et al., 2017; Sasahara et al., 2020).

However, the internal carotid artery is not present in all rodents and shows atresia in species such as the brown rat, the spiny mouse, or in the world's largest rodent, the capybara, in which it disappears during ontogenesis before adulthood (Steele et al., 2006, Szczurkowski et al., 2007; Esteves et al., 2013). As in Suidae, the phenomenon of obliteration of the extracranial segment of the internal carotid artery occurs in almost all species of the infraorder of higher ruminants (Pecora), where its only remnant is its intracranial segment as a continuation of the rostral epidural rete mirabile (Frąckowiak et al. 2015; O'Brien et al. 2016; Zdun and Frąckowiak, 2019; Graczyk and Zdun, 2021). Similarly, in the domestic cat, involution of the extracranial segment of this artery takes place before adulthood (Ziemak et al., 2021). Frąckowiak and Godynicki (2003) demonstrated the obliteration of this segment in other Felidae species: the African lion, tiger, Bengal cat, puma and leopard.

Despite the common occurrence of obliteration of the external carotid artery, its exact cause has not been determined. According to (Zedenov, 1937), it may be linked to the change in the relative positions of the tympanic bulla and the petrous part of the temporal bone in ontogenesis, resulting in exclusion of the vessels from the middle ear region and thus the elimination of low-frequency sounds associated with the pulse wave. In the domestic pig, this hypothesis is strongly supported by the fact that the minimum audible frequency in this species is 42 Hz (Heffner and Heffner, 1990). In the capybara, the lumen of the carotid artery atrophies at about 12 months of age, leaving as a remnant a ligamentous cord. The atrophy takes place through the growth of soft tissue (serous membrane) with the infiltration of a large number of collagen fibres and through atrophy of the muscle tissue to 1-2 layers; in addition, the growth of adipose tissue in the proximity of the atrophied artery has been observed. The cause of obliteration was thought to be the cessation of blood supply to the forebrain via the internal carotid artery, rendering the role of the artery negligible (Steele et al., 2006). These changes were reflected in the remodelling of the basilar artery by an increase in its lumen and blood pressure, accompanied by an increase in pressure in the larger vessels of the brain, e.g. the rostral communicating artery, which intensified the process of atrophy of the internal carotid artery. These changes were observed most intensively in the species between 6 and 12 months of age (Reckziegel and Lindemann, 2017).

A precise description of this region is not only of general biological interest, but of clinical interest as well. According to some authors, the domestic pig may be one of the best examples of a laboratory animal in studies on anatomy, functional genomics and various diseases, including atherosclerosis or cardiovascular diseases, due to the similarity of many organs to human organs (Smorąg et al., 2011; Swindle et al., 2012; Hager and Rekiel, 2016). The paired rostral cerebral arteries of the brain and the paired caudal communicating arteries, which are components of the cerebral arterial circle, are initiated by the intracranial segment of the internal carotid artery, derived from the rostral epidural rete mirabile. The rete itself, on the other hand, is formed by a branch to the rostral epidural rete mirabile, and to a lesser extent by branches to the rostral epidural rete mirabile of the maxillary and external ophthalmic artery. The second and final source of arterial blood to the brain is the basilar artery, which has a direct connection to the aforementioned cerebral arterial circle (Frąckowiak, 2003). Therefore, the cerebral vasculature of the domestic pig also seems to play an important role in the context of disorders associated with cerebral circulation in humans, i.e. cerebral ischaemic strokes or hypothermia. Mangla et al. (2015) obtained very similar cerebral perfusion in adult pigs as in a human model; however, the presence of the rostral epidural rete mirabile and increased perfusion of the external carotid artery depressed cerebral blood flow. Modification of blood flow through embolization of the external carotid artery led to a significant increase in the cerebral blood flow rate, manifested as an increase in cooling of the affected hemisphere by 288 ± 88%.

The presence of atherosclerotic plaques, blood clots or foreign bodies in the vessels can lead to the development of cerebral ischaemic stroke, but this problem can be quickly resolved by replacing major cerebral arterial inflows with by-passes and closing the arterial lumen or performing an arteriovenous fistula. In a study on 16 pigs, Bates et al. (2003) measured the velocity of arterial blood flow through the internal carotid artery (this was the name given by the authors to the branch to the rostral epidural rete mirabile artery). In the control trial, the velocity of blood flow through the internal carotid artery was 92 ± 4,3 cm/sec. Following occlusion of the common carotid artery, the flow decreased significantly to 29,7 ± 1,6 cm/sec. The occlusion of the common carotid artery and external carotid artery completely stopped the blood flow in the internal carotid artery. Only occlusion of the external carotid artery and creation of an arteriovenous fistula enabled reverse blood flow from the internal carotid artery towards the heart, where the reverse flow rate was 24,6 ± 4,3 cm/sec, increasing to 90 ± 2,6 cm/sec after additional continuous syringe aspiration and to 119,9 ± 8,8 cm/sec after intermittent aspiration. These findings are particularly important in the case of a microembolism in the cerebral region and reversal of blood flow to reduce the risk of ischaemic stroke and subsequent brain damage or death, so that knowledge of the exact course and layout of the vessels supplying the brain is essential. Owing to such models of intravascular intervention in animals, the incidence of these conditions in humans can be similarly reduced.

CONCLUSIONS

The internal carotid artery branches off in a common trunk with the occipital and condylar artery and then gives off an extracranial segment that passes into the tympanic cavity.

Due to its very small lumen, the role of the internal carotid artery in supplying the brain is negligible, and thus it also does not influence the shape of the rostral epidural rete mirabile.

Obliteration of the internal carotid artery begins at 8 months of age and involves the initial segment of the artery, and ends when the animal is 9 months old with the final segment.

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