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The internal carotid artery in the ontogenesis of selected representatives of the Cervidae family in Poland

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SUMMARY

Cervids present in the natural environment of Poland include red deer, fallow deer, Eurasian elk, and roe deer. In ruminants, during ontogeny changes occur in the arterial system of the head, involving obliteration of the extracranial segment of the internal carotid artery. The aim of this study was to describe the presence and course of the internal carotid artery and establish the timing of changes in the vascular system of the head associated with the obliteration of this vessel. The study was conducted on 146 representatives of the Cervidae family: red deer, fallow deer and roe deer. The presence of a fully preserved internal carotid artery was shown in foetuses and young animals up to the age of about two years. At about 2.5 years of age, only the initial part of the internal carotid artery, emerging from the carotid sinus, and a short fragment directly before the rostral epidural rete mirabile were preserved. In adult animals older than three years, the extracranial part of this artery was obliterated.

KEY WORDS: artery, fallow deer, red deer, roe deer

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INTRODUCTION

The family Cervidae brings together numerous species of animals inhabiting geographic extremes from the tundra to the equatorial zone. The Cervidae, alongside the Bovidae, constitute one of the largest families in the order Artiodactyla in terms of number of species. The order consists of three suborders – Ruminantia, Tylopoda and Suiformes (Wilson and Reeder, 2005), with Cervidae included in the Ruminantia. Cervids present in the natural environment of Poland are the European red deer (*Cervus elaphus*), fallow deer (*Dama dama*), Eurasian elk (*Alces alces*) and roe deer (*Capreolus capreolus*).

The rostral epidural rete mirabile is present in the internal carotid artery of artiodactyls. To describe the internal carotid artery in ruminants, it is very useful to divide it into pre-retial, intra-retial and supra-retial segments (Godynicki et al., 1996). In ruminants, changes occurring during ontogeny in the arterial system of the head, involving obliteration of the extracranial (pre-retial) segment of the internal carotid artery, have been described in domestic cattle (Zedenov, 1937; König, 1979) and numerous other species of tribe Bovini (Zdun et al., 2013). The developmental changes result in severing of the junction of the common carotid artery with the rostral epidural rete mirabile. The intracranial segment of the internal carotid artery is not affected. The extracranial segment is preserved throughout the life of Siberian muskrats of the infraorder Pecora (Frąckowiak, 2003) and Tragulinae belonging to the infraorder Tragulina (Fukuta et al., 2007). In camelids, the extracranial part of the internal carotid artery is present both during foetal life and in adults (Kieltyka-Kurc et al., 2014). In the domestic pig and Eurasian wild boar, obliteration of this part of the vessel also occurs at nine months of age (Graczyk et al., 2022). In animals other than artiodactyls, a similar phenomenon has been observed in the cat, at the age of 4–8 weeks (Ziemak et al., 2021). The differences observed among even-toed ungulates prompted the authors of the present study to analyse the changes occurring during individual development in selected Cervidae representatives.

The aim of this study was to describe the presence and course of the internal carotid artery and indicate the timing of changes in the vascular system of the head associated with the process of obliteration of this vessel.

MATERIAL AND METHODS

The study was conducted on 146 representatives of the Cervidae family, of both sexes. The specimens were divided into three groups: 59 foetuses with a crown–rump length of 76–329 mm (28 red deer, 26 fallow deer, and 5 roe deer), 25 juvenile animals aged from newborn to two years (10 red deer, 10 fallow deer, and 5 roe deer), and 62 animals older than two years (28 red deer, 22 fallow deer, and 12 roe deer). The cadavers were obtained from private breeders, slaughterhouses and hunters.

A total of 121 randomly selected cadavers were processed by injecting a stained solution of the chemically bonded acrylic material Duracryl® Plus into the common carotid arteries. After a short time (15–20 min) necessary for setting, the specimens were enzymatically macerated with Persil® powder diluted in water at 42°C for about one month. This procedure resulted in corrosion castings of the vessels on a bone scaffold (without the animal's tissues, other than bones). The second method, applied for 25 specimens, consisted in injecting stained liquid latex LBS 3060 into both common carotid arteries, leaving it to set in a 5% formalin solution for two weeks, and then preparing the blood vessels manually using surgical instruments during dissection in order to view them within the tissue.

The names of the anatomical structures were standardized according to *Nomina Anatomica Veterinaria* (2017).

RESULTS

The internal carotid artery in the Cervidae species analysed in the study is one of the sources of blood to the rostral epidural rete mirabile. From this rete emerges the intracranial segment of the internal carotid artery, which contributes to the formation of the cerebral arterial circle. In addition, the rostral epidural rete mirabile is supplied by the rostral branches to the rostral epidural rete mirabile and by the caudal branch to the rete, which diverges from the maxillary artery. Rostral branches to the rete departing from the external ophthalmic artery were also observed. On the caudal side, a branch of the condylar artery was attached to the rete departing from the occipital artery. Analysis of the material showed the presence of a fully preserved internal carotid artery in foetuses (Figure 1) and young animals up to the age of about two years (Figure 2) in all species analysed.

Figure 1. The internal carotid artery in a red deer foetus. Corrosion cast.
1 – common carotid artery; 2 – external carotid artery; 3 – internal carotid artery; 4 – rostral epidural rete mirabile

Figure 2. The internal carotid artery in a 6-month-old roe deer. Corrosion cast.
1 – common carotid artery; 2 – external carotid artery; 3 – internal carotid artery

In foetuses and animals up to 6 months of age, the internal carotid artery diverged from the common carotid artery without any obvious thickening at the point of departure. The vessel headed towards the skull, entering between the petrous part and the tympanic bulla of the temporal bone pyramid. It then changed direction by 180°, like an inverted U, and headed through the petro-occipital fissure into the cranial cavity, where it was connected to the rostral epidural rete mirabile on its caudal side. In animals from one year of age, a small protrusion, the carotid sinus, from which the stroma of the internal carotid artery emerged, was observed at the exit of the internal carotid artery. On three specimens of red deer and two specimens of fallow deer of about 2.5 years of age (Figure 3), only the initial fragment of the internal carotid artery, emerging from the carotid sinus, and a short fragment directly before the rostral epidural rete mirabile were preserved. The middle fragment of this vessel was not patent, indicating obliteration beginning in the middle part of the internal carotid artery. Only the intracranial segment of the internal carotid artery was found emerging from the rostral epidural rete mirabile in adult animals older than three years. The extracranial segment of the external carotid artery in these animals was obliterated. Thus, the connection between the rostral epidural rete mirabile and the common carotid artery had ceased to function.

Figure 2. The internal carotid artery in 2.5-year-old fallow deer. Corrosion cast. 1 – common carotid artery; 2 – external carotid artery; 3 – internal carotid artery.

DISCUSSION

The absence of an extracranial part of the internal carotid artery in Cervidae species has been noted in adult reindeer, chital, Eld's deer, wapiti, sika deer, fallow deer, milu and Chinese muntjac (Kieltyka-Kurc et al., 2015), as well as Eurasian elk (Zdun et al., 2019). In this last species, the internal carotid artery was fully preserved in juvenile specimens (Zdun et al., 2019). The results of our study also confirm complete obliteration of the extracranial part of this vessel in adult Cervidae. The inclusion of foetal and juvenile specimens in the study made it possible to trace the internal carotid artery during prenatal and postnatal ontogeny and to demonstrate its presence and connection to the rostral epidural rete mirabile. All foetuses with a crown-rump length of 76–329 mm were shown to have a fully preserved internal carotid artery, with all pre-retial, intra-retial and supra-retial segments. The condition of the internal carotid artery was similar from the beginning of the postnatal period, i.e. in newborn animals up to the age of about two years.

The internal carotid artery remains preserved in foetuses and newborn cattle (König, 1979; Simoens et al., 1987; Zdun et al., 2013). König (1979) reports that Schmidt in 1910 detected the presence of the internal carotid artery in calves at 6–8 weeks of age. Some artiodactyls, such as goats and sheep, lose a patent internal carotid artery shortly after parturition (Daniel et al., 1953), and still others, such as cattle and oxen, lose it before sexual maturity (Daniel et al., 1953; Gillilan, 1974; Bamel et al., 1975).

The phenomenon of obliteration of the extracranial part of the internal carotid artery, or the presence of a vessel with a very narrow lumen with no significant role in supplying blood to the brain, has been found in some animals of the order of rodents: the porcupine (Aydin et al., 2005), capybara (Reckziegel et al., 2001; Frąckowiak, 2003), guinea pig (Jabłonski, 1980; Ocal and Ozer, 1992), common degu (Brudnicki et al., 2014), American nutria (Azambuja et al., 2018), chinchilla (Kuchinka, 2017) and red squirrel (Aydin, 2008). In general, it can be concluded that overgrowth of the extracranial segment of the internal carotid artery in rodents occurs in species of the families Agutiidae (Dasyproctidae), Hystricidae, Caviidae, Myocastoridae and Chinchillidae (Frąckowiak, 2003).

The obliteration of the extracranial segment of the internal carotid artery described in even-toed ungulates has also been demonstrated in some species of the order Carnivora: in the domestic cat (Takemura, 1982; Ziemak et al., 2021), lion (Frąckowiak, 1989; Hsieh and Takemura, 1994) and other Felidae species (Frąckowiak and Godynicki, 2003).

Żedenov (1937) attributed the cause of obliteration of the internal carotid artery in ruminants to a shift of the eardrum portion of the temporal bone during ontogeny. Comparative studies using foetal specimens confirmed a change in the topography of the course of the extracranial part of the external carotid artery in relation to the middle ear. The changes result in the exclusion of blood vessels from the middle ear and, consequently, the elimination of factors that emit interference with the reception of low-frequency sounds. This process in ruminants results in a complete involution of the extracranial (pre-retial) part of the internal carotid artery.

In the horse, donkey and dog, the course of the internal carotid artery is straight and does not form a bend before entering the cranial cavity. In equids, the vessel runs on the dorsal and rostral surface of the medial compartment of the guttural pouch. It passes through the lacerum foramen in equids or the jugular foramen in dogs (Du Boulay et al., 1975; Nanda, 1975; Gillilan, 1976; Khairuddin et al., 2017). It then enters the cranial cavity, passing through the ventral petrosal sinus and the venous cavernous sinus, forming an S-shaped curve (Colles and Cook, 1983; MacDonald et al., 1999). Thus, it does not pass between the eardrum and scalene parts of the temporal bone and thus does not interfere with sound perception, as pointed out by Zedenov (1937). A preserved internal carotid artery is also found in dolphins or narwhals. However, this vessel extends into the tympanic cavity, passing through the middle ear in a semi-circular arc (Vogl and Fisher, 1981; Cozzi et al., 2017). Hearing is well known to be the most important sense for these marine mammals, and they use it to emit and receive infrasound. It may be surmised that the obliteration of this vessel in ruminants is not related to their emission of low-frequency sounds but is merely the result of developmental changes associated with the change in the position of the eardrum portion of the temporal bone. To confirm this, it would be necessary to compare the frequency range of the waves emitted by the vessel with the range of perceived sounds in these aquatic mammals, but Zedenov (1937) does not specify such a range.

In addition to the obvious role of this vessel in supplying blood to the brain, other roles of this vessel have also been considered. Maloney et al. (2002) sought to test the hypothesis of a role of the internal carotid artery in the selective cooling of the brain in the horse. The hypothesis relied on the heat exchange between the blood in the vessel and the air sac it passes through. However, the authors themselves stated that if the contact between these structures is assumed to account for about 6% of the surface area of the sac, the air cannot flow through the air sac in such a way that the blood temperature in the vessel can be realistically reduced. The phenomenon of selective cooling of the brain has been described in ruminants. However, it involves the rostral epidural rete mirabile and the venous cavernous sinus, but not the internal carotid artery. Cooler venous blood returning from the nasal cavity washes over the vessels of the rete mirabile, causing a drop in the temperature of arterial blood flowing into the brain (Hayward and Baker, 1969; Strauss et al., 2017).

In addition, it is important to note the serpentine course of the intracranial portion of this artery. According to Ruedi (1922), the likely function of this fragment in the domestic horse is to attenuate the pulse wave of arterial blood and protect the brain from a surge of pressure. In horses, there is no rostral epidural rete mirabile to perform this function.

CONCLUSIONS

This study showed the presence of a fully preserved internal carotid artery in foetuses and young animals up to the age of about two years. In animals of about 2.5 years of age, only the initial fragment of the internal carotid artery, emerging from the carotid sinus, and a short fragment directly before the rostral epidural rete mirabile were preserved. In adult animals older than three years, the extracranial part of this artery was obliterated.

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