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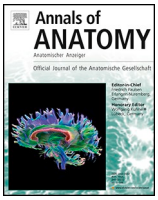

Internal carotid artery dolichoarteriopathies in the horse: An endoscopic and anatomic study

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ABSTRACT

Endoscopy of the guttural pouches in neonatal foals occasionally reveals atypical aspects in the course of the extracranial internal carotid arteries (ICAs) that are hardly seen in adult horses. While in veterinary medicine the data available on the presence of these anomalies in domestic mammals are limited and incomplete, in human medicine the morphological aspects of the ICAs have been the subject of extensive studies. Anomalies in the course and geometry of ICAs are commonly defined as dolichoarteriopathies, and should be classified as tortuous, kinked or coiled. To document whether the anomaly ICAs in foals can be attributed to dolichoarteriopathies, and to assess the incidence of carotid anomalies, two studies were conducted. An endoscopic study of the guttural pouch was carried out on 50 foals (24 M and 26 F) < 4w of age to examine the course of those ICAs in close contact with the pouch and an anatomical study was performed on the heads of 20 fresh horse carcasses (13 one-month-old foals, 1 seven-month-old and 6 adults) using vascular casts of the extracranial tracts of the ICAs to examine their morphology. The results showed the presence of ICA anomalies, including tortuosity, kinking, or coiling, only in foals < 4w olds and their absence in adults. The presence of a specific geometry in the foal was confirmed by both endoscopic and anatomical studies with 66 % and 71 % of the animals having dolichoarteriopathies, respectively, with a predominance of bilateral cases. Tortuosity was more common, and there appeared to be no gender difference in susceptibility. These anomalies could arise from the excessive length of the ICA in the extracranial course in relation to the distance between the origin of the vessel and its entry into the cranial cavity and based on this hypothesis, tortuosity, kinking and coiling in foals should be considered a simple transient anatomical variability and not a pathological event.

1. Introduction

The guttural pouch of the horse is a significant and intricate anatomical structure that constitutes an auditory tube diverticulum, which connects the throat to the ear. A comprehensive understanding of the normal anatomy and age effects on the guttural pouch are important because many structures within (specifically vessels and cranial nerves) can be altered or damaged by diseases, such as gutturomycosis and empyema, resulting in neurological signs and haemorrhage.

Endoscopy is the examination of choice to check the integrity of the guttural pouches. In adult horses and donkeys, endoscopic examinations have occasionally showed atypical aspects in the course of the extracranial internal carotid arteries (ICAs) (Bonilla et al., 2015; Hardy and Léveilé, 2003; Khairuddin et al., 2015; Macdonald et al., 1999). Other studies, anatomical (Nurul, 2011) or using diagnostic techniques such as ultrasound (Fogaça et al., 2020) and angiography (Khairuddin et al., 2015), have also shown interest in the equine carotid arteries and ICA's in particular.

In human medicine, the morphological aspects of the ICAs have been the subject of many studies since the early 1960s (Amidzic and Tiro, 2020; Beigelman et al., 2010; Del Corso et al., 1998; Dogalbayev et al., 2024; Golovin et al., 2023; Huang et al., 2024; La Barbera et al., 2006; Martins et al., 2018; Metz et al., 1961; Mumoli and Cei, 2008; Pellegrino et al., 2002; Pfeiffer and Ridder, 2008; Sho et al., 2004; Togay-Işikay et al., 2005; Weibel and Fields, 1965; Yu et al., 2017). The anomalies in the course and geometry of the ICAs, commonly defined as

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dolichoarteriopathies, were classified according to their shape and angulation as follows: Tortuosity has been classified into elongation, redundancy and undulation, depending on whether the ICA develops one or more loops and assumes an 'S' or 'C' shape. In some cases, the tortuous type includes the coiling or kinking type; Coiling is characterized by elongation of the ICA in a confined space, causing tortuosity and resulting in a 'C', 'S' or 'U' shape or a circular (or double circular) configuration; Kinking, angulation of one or more segments of the ICA with an internal angle $\leq 90°$. Furthermore, kinking can be divided into three grades. Grade I abnormality indicates an acute angle of 90°-60° between the two segments forming the kink, grade II indicates an angle of 60°-30°, and grade III indicates an angle less than 30°. Kinking and coiling can transition into other DICA types depending on the imaging projection, and mixed forms of DICAs can occur (Beigelman et al., 2010; Metz et al., 1961; Weibel and Fields, 1965). The aim of the present study was to verify whether different ICAs geometry in foals could be comparable to the dolichoarteriopathies described in humans, to assess the frequency of carotid anomalies, and to verify whether the presence of these atypical features was age dependent.

2. Material and methods

A two-fold investigation was carried out at the level of the parotid region. An endoscopic study of the guttural pouch was carried out on 50 foals of different breeds (Table 1) and under four weeks of age to examine the course of the ICAs in close contact with the pouch. An anatomical study was carried out on 13 one-month-old foals, one seven-month-old foal and six healthy adult horses of different breeds (Table 2), using vascular casts of the extracranial tract of the ICAs in order to examine their morphology.

The study was assessed by the Animal Welfare Committee of the University of Bologna which provided a positive ethical-scientific evaluation and confirmed its compliance with national laws on the topic.

3. Endoscopy of guttural pouches

An endoscopic examination of the guttural pouches and upper respiratory tract was performed on 50 foals (24 male and 26 female) under 30 days of age, born from mares hospitalized for attending parturition, or admitted to the Veterinary Teaching Hospital with respiratory symptoms. An examination of guttural pouches was carried out using a flexible video endoscope having a 6 mm sheath diameter (Pentax EG 1840) and were evaluated in real time and recorded.

Table 1 –
Breed, sex, age and internal carotid artery (ICA) shape in the foals subjected to endoscopy.

			ICA shape	
Breed	**Sex**	**Age in days**	**Left side**	**Right side**
Standardbred (13) Appaloosa (2) Quarter Horse (1) Arabian (1)	8M-9F	2–15	Linear	Linear
Standardbred (5) Mixedbred (1)	2F-4M	1–7	Tortuosity	Tortuosity
Italian Saddlebred (1)	M	3	Coiling	Coiling
Standardbred (5)	4F-1M	3–11	Kinking	Kinking
Standardbred (4) Arabian (2) Quarter Horse (1)	6F-1M	2–7	Tortuosity	Linear
Italian Saddlebred (1)	M	4	Coiling	Linear
Standardbred (4) Italian Saddlebred (1)	4M-1F	1–4	Kinking	Tortuosity
Standardbred (1)	1 M	3	Tortuosity	Coiling
Standardbred (2)	2 F	3–4	Coiling	Tortuosity
Standardbred (2) Quarte Horse (1)	1M-2F	1–7	Kinking	Coiling
Standardbred (2)	2 F	2–3	Coiling	kinking

Table 2 -
Breed, sex, age and internal carotid artery (ICA) shape in the horses undergoing the anatomical study.

			ICA shape	
Breed	**Sex**	**Age**	**Left side**	**Right side**
Standardbred (1)	M	1 d	Kinking	Tortuosity
Shetland Pony (1)	F	1 d	Tortuosity	Linear
Shetland Pony (1)	F	1 d	Linear	Linear
Arabian (1)	F	1 d	Tortuosity	Coiling
Standardbred (1)	M	1 d	Linear	Tortuosity
Standardbred (1)	F	1 d	Tortuosity	Tortuosity
Italian Saddlebred	M	3 d	Tortuosity	Coiling
Standardbred (1)	M	5 d	Kinking	Coiling
Standardbred (1)	F	7 d	Linear	Linear
Italian Saddlebred (1)	F	7 d	Kinking	Kinking
Appaloosa (1)	M	20 d	Tortuosity	Linear
Standardbred (1)	F	28 d	Kinking	Tortuosity
Standardbred (1)	M	28 d	Linear	Linear
Standardbred (1)	M	7 m	Linear	Linear
Standardbred (6)	3M-3F	> 5 y	Linear	Linear

To carry out the examination, the foal was restrained without sedation in lateral recumbency on a table near the mare at the operator's height. The position of the head and neck was maintained in accordance with the physiological norm and flexion-extension movements were performed to ensure that the position of the head did not alter the conformation of the vessels.

Penetration into the guttural pouch occurred by moving the tip of the endoscope in a dorsal-lateral direction with the help of a catheter introduced through the working channel.

Once the endoscope had been introduced into the initial funnel-shaped canal and the catheter extracted, the examination of the guttural pouch, divided by the stylohyoid bone into medial and lateral compartments, began. The course of the internal carotid artery was examined during the examination of the medial compartment, classifying it as reported by Weibel and Fields (Weibel and Fields, 1965) into linear, tortuous, kinked or coiled.

Once the examination of the guttural pouch had been completed, after having moved the optic back into the pharynx, the endoscope was completely extracted, the foal was positioned on the contralateral side, and the procedure was repeated for the other guttural pouch.

4. Anatomical study

The heads and necks of 20 fresh equine carcasses of various breeds and of both sexes were examined, including 13 one-month-old foals (6 males and 7 females) and one seven-month-old male foal died spontaneously at the Veterinary Teaching Hospital from causes unrelated to respiratory disease, and six healthy adult horses (3 males and 3 females) destined for human consumption and obtained from a local slaughterhouse. All of the guttural pouches were free from disease.

Each specimen was placed in left lateral recumbency with the head and neck at an angle as close as possible to the physiological position (90°).

According to a procedure described elsewhere (De Sordi et al., 2014), a cast of the common carotid artery and its branches was obtained by injecting 40 g of polyurethane foam (diphenylmethane-4,4-diisocyanate; Soudafoam® - Soudal N.V., Turnhout, Belgium) diluted with 10 ml of acetone (to prevent over-expansion) and with the addition of a few drops of red nitro dye (PebeoCeramic®, Gemenos Cedex, France). A plastic cannula was inserted into the caudal third of the common carotid artery for injection. After finishing the casting procedure, the specimens were stored at 4°C for four hours to allow the foam to harden.

Starting from the skin, a stepwise dissection of the lateral cervical, parotid and masseter regions was performed. In particular, the external jugular vein, the parotid and mandibular glands, the brachiocephalic and omohyoideus muscles were removed to expose the common carotid

artery. The caudal part of the ramus of the mandible and the caudal belly of the digastric and stylohyoid muscles were then removed to reveal the three terminal branches of the common carotid artery (occipital, internal and external carotid arteries).

In particular, the relationship between the ICA and the occipital artery and the course of the artery in relation to the surrounding structures, especially the guttural pouch, were assessed.

Flexion-extension movements were performed to ensure that the position of the head did not alter the conformation of the vessels. No changes in the shape of the ICA were observed.

The same procedure was repeated on the right side.

Anomalies in the length and angulation of the ICAs were classified according to the criteria of Weibel and Fields(Weibel and Fields, 1965).

Images were acquired using a reflex digital camera (Fujifilm HS50) and were processed with Adobe Photoshop CS7®.

5. Results

Both the endoscopy and the anatomical study confirmed the presence of extracranial ICAs of different shapes in the subjects under one month of age. These anomalies were similar to those associated with dolichoarteriopathies, namely tortuosity, kinking and coiling (Fig. 1). (Weibel and Fields, 1965)

Endoscopic study - Of the 50 foals, 33 (66 %) had ICA anomalies; 17 were female and 16 were male. Of these, 25 (75.7 %) had bilateral and 8 (24.3 %) had unilateral dolichoarteriopathies. In particular, the latter always involved the left ICA. The most common anomaly was tortuosity (42 arteries, 46.5 %), followed by kinking (20 arteries, 34.5 %) and coiling (11 arteries, 19 %) (Fig. 2). See Table 1 for details.

Anatomical study – The dissection showed that, in most cases, the ICA originated from the terminal common carotid artery, just before the origin of the occipital artery and the continuation of the common carotid artery into the external carotid artery. In two foals, however, the ICA originated from a short common trunk with the occipital artery (Fig. 3).

Internal carotid artery anomalies were found in 10 (71 %) of the 14 foals: five females and five males. Of these, seven (70 %) showed bilateral and three (30 %) unilateral dolichoarteriopathies (one right and two left arteries). The most common anomaly was tortuosity (nine arteries, 53 %), followed by kinking (five arteries, 29 %) and coiling (three arteries, 18 %) (Fig. 4). In the six adult horses, the course of the ICA was linear (Fig. 5). Table 2 summarizes the details of the study population.

6. Discussion

The technique of producing the anatomical casts proved to be effective, thereby confirming the results previously described in several studies in horses and other species (De Sordi et al., 2014; Grandis et al., 2021; Martín-Orti et al., 2022; Nurul, 2011; Ramadani et al., 2022; Shanthini and Suma, 2019).

The anatomical study showed that the origin of the ICA was consistent with that described in the literature in horses (Barone, 2021; Khairuddin et al., 2015; Macdonald et al., 1999; Nurul, 2011). In particular, in accordance with the 10 % rate reported in the literature (Barone, 2021; Khairuddin et al., 2015; Nurul, 2011), the common carotid artery in two subjects terminated by giving rise to the external carotid artery and a short common trunk from which the occipital and internal carotid arteries originated shortly thereafter.

With regard to the conformation of the extracranial ICAs, the endoscopic and the anatomical studies both confirmed the presence of a specific geometry in the foal which could be attributed to the so-called dolichoarteriopathies described in humans (Foiadelli et al., 2020; La Barbera et al., 2006; Martins et al., 2018; Metz et al., 1961; Mumoli and Cei, 2008; Nagata et al., 2016; Pfeiffer and Ridder, 2008; Sho et al., 2004; Weibel and Fields, 1965; Yu et al., 2017). The percentage of animals with dolichoarteriopathy was 66 % and 71 % in endoscopic and anatomical studies, respectively, with a predominance of bilateral cases. In addition, in the unilateral cases, the left ICA was for the most part, if not exclusively (endoscopic study), involved. Some authors claim that internal carotid artery dolichoarteriopathies (DICAs) are more common on the left side (Del Corso et al., 1998; Di Pino et al., 2021; Martins et al., 2018; Togay-Işikay et al., 2005), while others state that there is no difference between the left and right ICAs (Dilba et al., 2021; Nagata et al., 2016). The reason for this prevalence is still under debate.

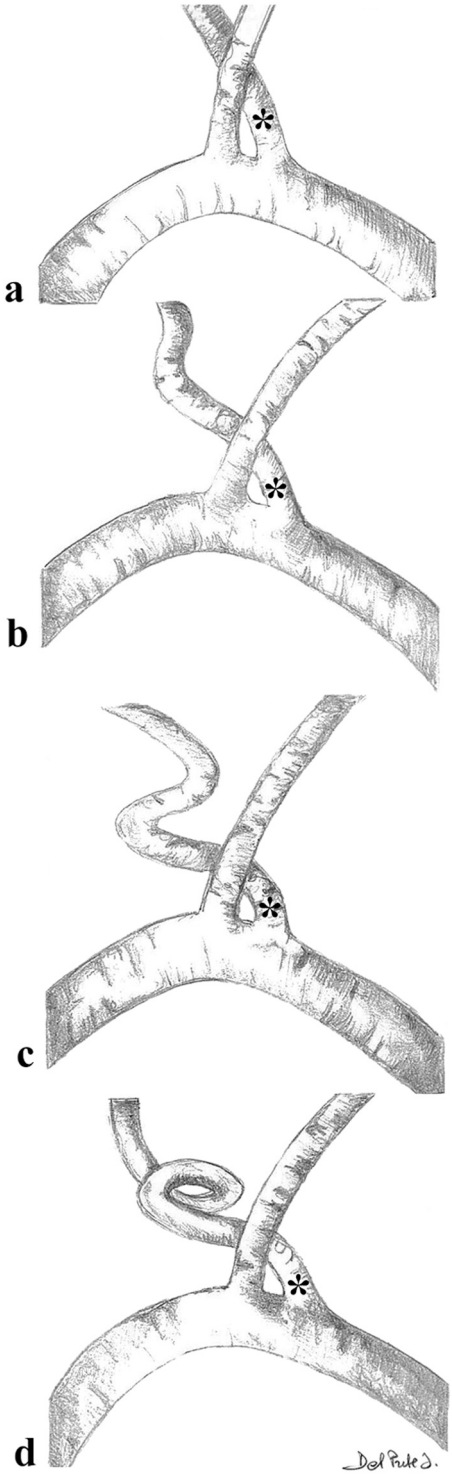

Fig. 1. Schematic drawing of the different types of extracranial internal carotid arteries (ICAs) (**asterisk**) according to the classification of Weibel and Fields (1965): **a**, linear; **b**, tortuous; **c**, kinking; **d**, coiling.

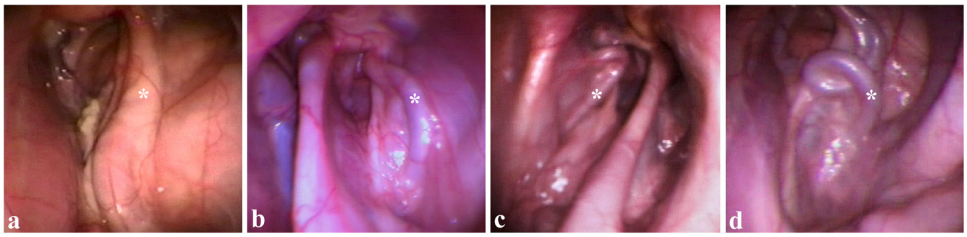

Fig. 2. Endoscopic views of the medial compartment of the guttural pouch showing the course of the internal carotid artery (ICA) (**asterisk**). **a**, linear (right artery); **b**, tortuous (right artery); **c**, kinking (left artery); **d**, coiling (right artery).

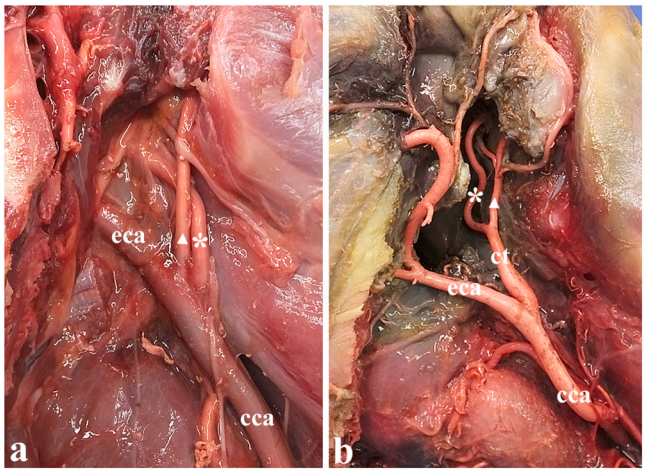

Fig. 3. Origin of the ICA; left side. In **a**, the internal carotid artery (ICAs) (asterisk) originates from the common carotid artery (**cca**) just before the occipital artery (**triangle**) emerges. In **b**, the ICA (**asterisk**) and the occipital artery (**triangle**) originate from a common trunk (**ct**). The **cca** continues as an external carotid artery (**eca**).

However, it is thought to be related to the difference in embryonic development of the arteries on both sides (Jansen van Vuuren et al., 2017; Kamath, 1981).

There also appears to be no gender difference in susceptibility to ICA anomalies. This is different from the condition described in humans in which the situation is controversial. In fact, the majority of authors state that females are more affected than males (Del Corso et al., 1998; Di Pino et al., 2021; Martins et al., 2018; Togay-Işikay et al., 2005), while only a few claim that there is no difference between the sexes (Pellegrino et al., 2002; Weibel and Fields, 1965) or that there is a predominance of males (La Barbera et al., 2006).

Based on the classification of three distinct types of dolicoarteriopathies proposed by Weibel and Fields (Weibel and Fields, 1965), tortuosity was more common than kinking and coiling in the horse, both on endoscopic examination and on dissection. This differed from what has been reported in humans where kinking was the most common form seen (Beigelman et al., 2010; Del Corso et al., 1998; Martins et al., 2018; Pfeiffer and Ridder, 2008; Togay-Işikay et al., 2005; Yu et al., 2017).

However, the most significant difference between humans and horses is the age of the subjects affected. In humans, dolichoarteriopathies mainly affect adults (Dilba et al., 2021) and gradually increase with age (Martins et al., 2018; Nagata et al., 2016). This anomaly is considered to be one of the pathological changes caused by vascular ageing and/or atherosclerotic remodeling, and is associated with cardiovascular risk factors (Del Corso et al., 1998; Dilba et al., 2021; Martins et al., 2018). Acquired causes also include cervical kyphosis and degenerative changes in the cervical spine (vertebral body and

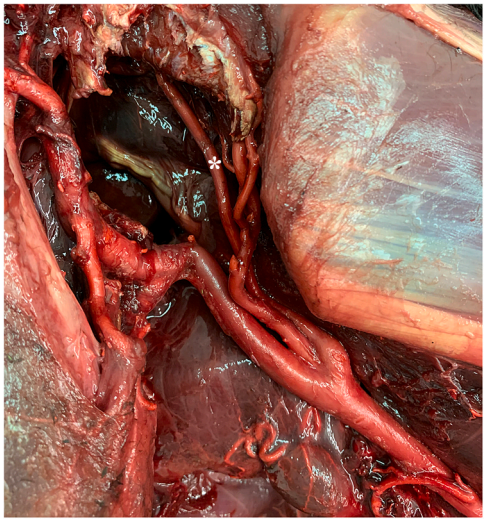

Fig. 5. Linear course of the internal carotid artery (ICA) (**asterisk**) in an adult horse. Left side.

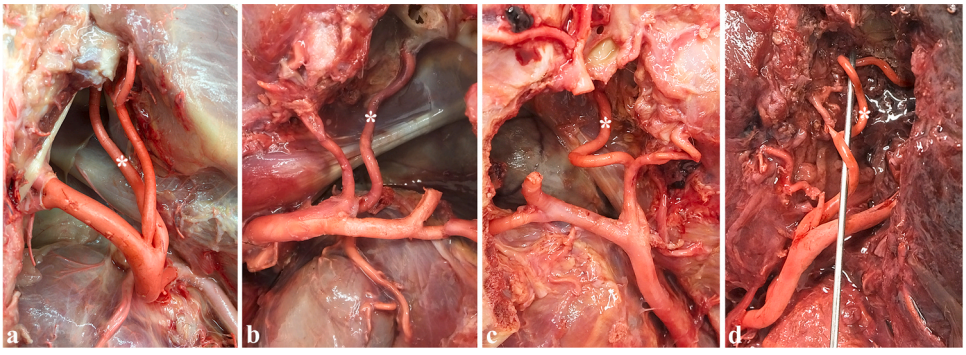

Fig. 4. Anatomical casts of different types of extracranial internal carotid arteries (ICAs) (**asterisk**) in foals. **a**, linear (left artery); **b**, tortuous (right artery); **c**, kinking (left artery); **d**, coiling (right artery).

intervertebral disc) which lead to neck shortening (Nagata et al., 2016).

Congenital causes have also been described in humans (Becker et al., 2014; Foiadelli et al., 2020). They are based on studies in which the same alterations have been found during intrauterine development, when the heart retracts into the mediastinum and the third arch of the aorta joins the dorsal aorta. In such studies, the prevalence also usually shows a similar frequency in all age groups, with no particular predisposition (Beigelman et al., 2010). La Barbera et al. (2006) and Foiadelli et al. (2020) also hypothesized that children with dolichoarteriopathies have concomitant connective tissue disorders.

On the other hand, in horses, the results of endoscopic and anatomo-topographical examinations have shown the presence of DICAs only in young subjects, and their absence in adults. Nevertheless, the latter result could be underestimated by the number of subjects examined. In this regard it is important to highlight the main limitation of the study, which is the narrow age range of the foals that precludes the possibility of determining when the ICA conformation begins to change. The ability to perform on the foal's serial endoscopy, in order to monitoring developments with a longitudinal prospective study, it would have been useful to verify the evolution of DICA. Anyway, based on these data, a congenital etiology can be hypothesized for this species. However, the congenital anomalies described in humans and horses differ significantly in their temporal evolution. In fact, in horses they disappear with growth, whereas in humans they persist throughout life. In horses, these anomalies could arise from the excessive length of the ICA in the extracranial course in relation to the distance between the origin of the vessel and its entry into the cranial cavity. This would lead to the formation of tortuosity, kinking and coiling due to the haemodynamic forces of the blood against the vessel walls (Sho et al., 2004). During growth, the elongation of the head and neck and the progressive increase in the volume and caudal extent of the guttural pouch can be assumed to cause distension of the ICA until the anomaly resolves. Similar considerations were made by Di Pino et al. (2021) who found that, in a population of 2856 subjects 0–96 years of age, ICA kinking decreased from 15.3 % in subjects under 20 years of age to 5.2 % in subjects 40–60 years of age.

Based on this hypothesis, tortuosity, kinking and coiling in foals should be considered a simple transient anatomical variability and not a pathological event. This is reinforced by the absence of any type of neurological symptomatology related to cerebral ischemia in foals with DICA, unlike what has been described in human medicine (Del Corso et al., 1998; Dilba et al., 2021; Martins et al., 2018).

It is known that guttural pouches are typical anatomical structures of Perissodactyls, the function of which has not yet been clarified (Baptiste, 1998; Hodgson, 1998; Manglai et al., 2000; Rooney, 1997). The most popular theory at present is that these structures are involved in the selective cooling mechanism of the encephalon (Baptiste et al., 2000; Mitchell et al., 2006). In fact, under conditions of high thermal stress, for example after intense and prolonged exercise, the pharyngeal ostia of the auditory tubes open to allow air to enter into the guttural pouches to ventilate them and cool the blood flow of the ICA. In particular, the flow of air into the guttural sacs would be able to lower the blood temperature by up to 2.3°C, avoiding critical levels which would cause irreversible brain damage (Baptiste, 1998).

In foals, the presence of anomalies in the course of the ICA resulted in an increase in the surface area of the vessel in direct contact with the guttural pouch as compared to subjects with a linear course. This could allow a more rapid cooling of the blood destined for the brain.

Finally, although concomitant elongation of the ICA and the common carotid artery has been described in humans (Govedarski et al., 2019), no anomalies of other arteries in the neck, apart from the ICA, were ever observed in the horses studied.

CRediT authorship contribution statement

Grandis Annamaria: Writing – review & editing, Visualization, Supervision, Project administration, Investigation, Conceptualization. **Bombardi Cristiano:** Writing – review & editing, Visualization, Conceptualization. **Canova Marco:** Methodology, Data curation. **De Silva Margherita:** Visualization, Validation. **Castagnetti Carolina:** Writing – review & editing, Visualization. **Cacchione Samanta:** Investigation, Data curation. **Tagliavia Claudio:** Writing – review & editing, Writing – original draft, Resources, Investigation, Formal analysis, Conceptualization. **Salamanca Giulia:** Visualization, Methodology. **Pietra Marco:** Writing – review & editing, Resources, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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