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Prevalence of dorsal notch and variations in the foramen magnum shape in dogs of different breeds and morphotypes

Marta Kupczyńska[1], Norbert Czubaj[1], Karolina Barszcz[1], Wojciech Sokołowski[1], Michał Czopowicz[2], Halina Purzyc[3]*, Małgorzata Dzierzęcka[1], Wojciech Kinda[4] & Zdzisław Kiełbowicz[4]

[1] *Warsaw University of Life Sciences – SGGW, Faculty of Veterinary Medicine, Department of Morphological Sciences, Nowoursynowska 159, 02-776 Warsaw, Poland*
[2] *Warsaw University of Life Sciences – SGGW, Faculty of Veterinary Medicine, Laboratory of Veterinary Epidemiology and Economics, Nowoursynowska 159, 02-776 Warsaw, Poland*
[3] *Wrocław University of Environmental and Life Sciences, Faculty of Veterinary Medicine, Department of Biostructure and Animal Physiology, Kożuchowska 5, 51-631 Wrocław, Poland; e-mail: halina.purzyc@up.wroc.pl*
[4] *Wrocław University of Environmental and Life Sciences, Faculty of Veterinary Medicine, Department of Surgery, Pl. Grunwaldzki 51, 50-366 Wrocław, Poland*

Abstract: The study evaluated shape of the foramen magnum (FM) in dog with regard to its constitutional type (small, medium and large breeds) and morphotype (brachycephalic, mesaticephalic and dolichocephalic dogs). We used multi-slice CT scanner to examine occipital area of 138 purebreds dogs. Two studied groups could be distinguished – living animals undergoing standard diagnostic CT procedure ($n = 47$) and macerated skulls of euthanized dogs ($n = 91$). Morphometric analysis was focused on presence of dorsal notch within foramen magnum. This anatomical feature was present in 33.3% of examined dogs. It was more often observed in small size dogs (70%) and those of brachycephalic morphotype (94.1%). For the first time dorsal notch was noted in breeds such as French Bulldog, Fox Terrier, Keeshond, Standard Schnauzer, English Bulldog, Cocker Spaniel, Boxer and Rottweiler. We distinguished four different shape of FM: oval, pentagonal, rhomboid and circular. Most common FM shape was oval (41 dogs; 45%) whereas circular type was least observed (5 dogs; 5.5%). The pentagonal shape was noticed in 27 specimens (29.7%) and the rhomboid shape in 18 dogs (19.8%). Authors conclude that dorsal notch is not pathology and should be considered a morphological variation within the normal anatomy. Results presented in this study should be taken into account during interpretation of the CT images of the craniocervical junction.

Key words: foramen magnum; occipital bone; dorsal notch; dog

Introduction

The foramen magnum is the biggest opening in the skull, located in the central part of the occipital bone. It is limited ventrally by the basilar part of occipital bone, laterally by the lateral parts of the occipital bone, and dorsally by the squama of the occipital bone (Evans & de Lahunta 2013). Many scientific papers in the field of veterinary medicine focus on the description of the occipital bone and the caudal cranial fossa, located at its inner surface, which includes the metencephalon (Simoens et al. 1994a, b; Onar et al. 1997; Chrószcz et al. 2006; Rusbridge & Knowler 2006; Janeczek et al. 2008, Wielądek & Kupczyńska 2008; Cross et al. 2009; Baroni et al. 2011; Janeczek et al. 2011). Some races experience disorders in the development of this structure, which may result in neurological symptoms. Parts of the brain may bulge through the foramen magnum and move towards the vertebral canal (Czubaj et al. 2015). For this reason, the foramen magnum has been of interest to researchers attempting to determine whether abnormalities in its morphology affect the incidence or severity of the symptoms. In some breeds of dogs, a dorsal notch occurs within the squama of the occipital bone, which is a dorsal extension of the foramen magnum, giving the structure an appearance of a characteristic "keyhole" (Parker & Park 1974; de Lahunta A. & Glass 2009; Evans & de Lahunta 2013). In the source literature, this condition is called occipital dysplasia (Parker & Park 1974; de Lahunta A. & Glass 2009). However, it has to be underlined that this term is debatable. Some researchers define the "dorsal notch" as pathology (Wright 1979; Sharp & Wheeler 2005) but others consider it a morphological variation that can be accepted as part of the normal anatomy of the domestic dog (Simoens et al. 1994a; Onar et al. 2013). There are also numerous publications in the field of human medicine that describe morphometry of

* Corresponding author

Table 1. Characteristics of the dog samples.

	Constitutional type		
	Small (S) ($n = 50$)	Medium (M) ($n = 32$)	Large and Giant (L&G) ($n = 56$)
Breed (n)	Yorkshire terrier (13), Dachshund (9), French Bulldog (7), Pekingese (6), Miniature Pinscher (4), Shih Tzu (2), Jack Russell Terrier, Chihuahua, Chinese Crested Dog, Fox Terrier, Schipperke, Whippet, Cavalier King Charles Spaniel, Pug (1 each)	Staffordshire Terrier (14), English Bulldog, Standard Schnauzer, Beagle, Dalmatian, Bullterrier, Australian Shepherd (2 each), Polish Hound, Keeshond, Samoyed, Cocker Spaniel, Springer Spaniel, Bavarian Mountain Dog (1 each)	German Shepherd (13), Boxer (11), Labrador Retriever (9), Rottweiler (5), Cane Corso (3), Doberman Pinscher, Great Dane (2 each) Golden Retriever, Leonberger, Belgian Sheepdog, Rhodesian Ridgeback, Black Russian Terrier, Bernes Mountain Dog, Newfoundland, German Wirehaired Pointer, St. Bernard, Swiss White Shepherd, Central Asian Shepherd Dog (1 each)

the foramen magnum. Furthermore, several papers also describe and classify the shape of the foramen magnum in individuals from various populations (Zaidi & Dayal 1988; Murshed et al. 2003; Kranioti et al. 2009; Richards & Jabbour 2009; Chethan et al. 2012; Natsis et al. 2013; Aragao et al. 2014). A lot of reports in the field of veterinary medicine focus solely on morphometric measurements of the foramen magnum and the presence of a dorsal notch.

The aim of this study was to present the characteristics of the foramen magnum in dogs belonging to various constitutional types. This publication also contains the first description of the presence of a dorsal notch in such breeds as the French Bulldog, Fox Terrier, Keeshond, Standard Schnauzer, English Bulldog, Cocker Spaniel, Boxer and Rottweiler.

Material and methods

The research was conducted on 138 adult purebred dogs (49% females), aged from 1.5 to 18 years (the median age was 8 years, and the interquartile range was from 6 to 11 years) from three different constitutional types (Table 1).

The observations were performed on two groups of animals. The first group included 91 individuals euthanized by veterinarians of the Small Animal Clinic of the Faculty of Veterinary Medicine at Warsaw University of Life Sciences or at private veterinary clinics in Warsaw. Having received consents from the owners of animals, the procedures were carried out in consequence of various, not neurological reasons. The owners also agreed that the corpses would be used for scientific purposes. According to the law in force in Poland, using a *post-mortem* obtained tissue does require an approval of the Ethics Committee. The corpses were then subjected to a process of maceration. Next the computed tomography of the skulls were performed at the Department of Surgery of the University of Environmental and Life Sciences in Wroclaw.

The heads of the remaining 47 individuals underwent computed tomography examination in the course of a diagnostic process, and included only individuals with no lesions observed within the skull. The images were taken with Siemens SOMATOM Emotion 16 CT Scanner and the measurements were performed with the use of Siemens syngo via software. The owners agreed to use the results of computed tomography examinations for scientific purposes.

Morphometric analysis of the foramen magnum

For each individual a cranial index value was calculated SI = ZyZy/AP × 100, where the cranial width (ZyZy) is the distance between the most laterally protruded points of the bilateral zygomatic arches, and the cranial length (AP) is the distance between the Akrokranion–Prosthion points (Evans & de Lahunta 2013). The Akrokranion is the most caudal point of the calvaria and the Prosthion is the most rostral point of the interincisive suture. The measurements were taken in the median planes for the AP measurement and in the frontal plane for the ZyZy measurement. On the basis of SI values, each individual was classified into one of three morphotypes: the dolichocephalic morphotype (SI < 50), the mesaticephalic morphotype (50–79) and the brachycephalic morphotype (≥80).

In the morphometric studies of the foramen magnum and of the squama of the occipital bone, the presence of each dorsal notch was reported. The following measurements were also taken: h – the height of the foramen magnum without the dorsal notch; W – the width of the foramen magnum, which is the distance between the most lateral points of the foramen magnum (Chrószcz et al. 2006; Wiełądek & Kupczyńska 2008; Janeczek et al. 2011). In the images obtained through computed tomography h and W measurements were taken in a plane close to the transverse plane, passing through the Basion and Opisthion line. The Basion is the point of the ventral border of the foramen magnum in the median plane and Opisthion is the point of the dorsal border of the foramen magnum in the median plane. The obtained data were used to calculate the index of the foramen magnum IOW = W/h × 100 (Chrószcz et al. 2006; Wiełądek & Kupczyńska 2008).

Analysis of the shape of the foramen magnum

The study of the foramen magnum shape was conducted only in euthanized dogs because only the observations made from the macerated skulls allow a reliable assessment of the shape of the foramen magnum. The research sample consisted of 91 individuals of which 46 were females. The age of the individuals ranged from 1.5 to 18 years with a median of 9 years and interquartile range from 7 to 13 years.

The characteristics of the research sample were very similar to the one presented in Table 1, only the sample size of each constitutional type was smaller: 31 dogs of small breeds, 23 dogs of medium breeds and 37 dogs of large and giant breeds.

Four shapes of the foramen magnum were distinguished: oval, rhomboid, pentagonal and round (Fig. 1). The dorsal notch, in individuals which had it, was not considered

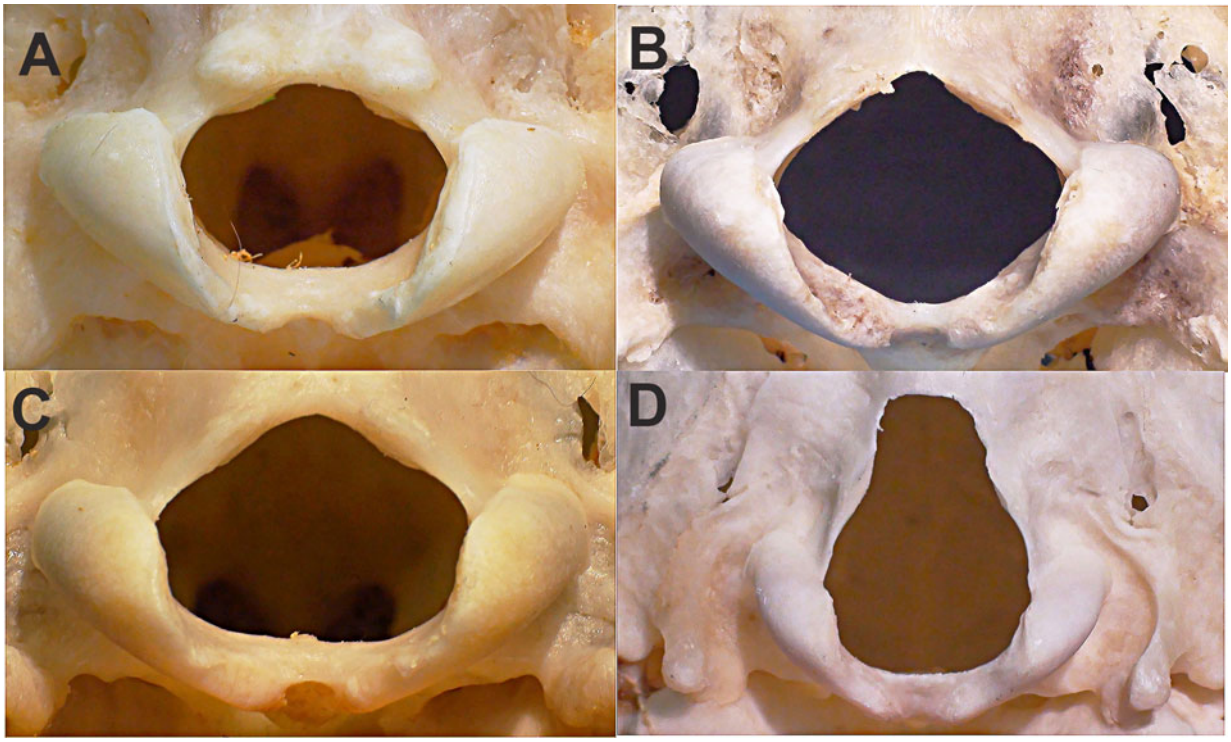

Fig. 1. Shape of the foramen magnum: A – oval, B – rhomboid, C – pentagonal, D – round.

in the assessment. The shape of the foramen magnum was only evaluated to the level of the lower border of the dorsal notch.

Statistical analysis

Numerical variables were given as means ± standard deviation (SD). A 95% confidence interval (95% CI) for proportions was calculated using the Wilson score method (Zar 2010). The comparison of SI and IOW between the constitutional types was carried out with either classical or Welch's one-way analysis of variance (ANOVA) depending on a Brown-Forsythe test result. Provided statistically significant ANOVA result, multiple comparisons were performed with a Tukey's post-hoc test for unequal sample sizes. The relationship between SI and IOW was evaluated using the Pearson's correlation coefficient. Links between prevalence of either dorsal notch or various shapes of the foramen magnum and the constitutional types or the morphotypes were investigated using a chi-square test for the linear trend with a modified post-hoc Tukey's test for proportions (Zar 2010). The relationship between quantitative variables and sex was analyzed with a Student t-test for unpaired samples. A two-tailed P-value below 0.05 was considered to indicate statistical significance. Graphs were prepared using Microsoft Office Excel 2007 and Statistica 10 software (StatSoft Inc.). The latter software was also used to perform statistical analysis.

Results

SI amounted to 62.7 ± 12.4 and there was a significant difference between the small dogs (69.8 ± 15.0) and other medium dogs (61.2 ± 8.9) ($P = 0.006$) and between the small and the large dogs (57.3 ± 8.0) ($P < 0.001$). The most common morphotype both in the entire studied population and in the particular constitutional types was the mesaticephalic morphotype (102/138 or 73.9% of dogs, with 95% CI 66.0%–80.5%). Additionally, in the small breed dogs the brachycephalic morphotype was present, while the dolichocephalic morphotype was not represented. In the large breed dogs, the situation was reversed; and the medium breed dogs belonged almost entirely to the mesaticephalic morphotype.

The dorsal notch was observed in 33.3% of the studied dogs (95% CI 26.0%–41.6%; 46/138). It occurred most frequently in the group of the small breed dogs (70.0%, 95% CI 56.3%–80.9%; 35/50), less frequently in the group of the medium-sized breed dogs (28.1%, 95% CI 15.6%–45.4%; 9/32), and only in two dogs of the large and giant breeds (3.6%, 95% CI 1.0%–12.1%) – in a Boxer and a Rottweiler. The differences were statistically significant ($P = 0.005$) (Fig. 2).

The dorsal notch was also present in 94.1% of the brachycephalic dogs (95% CI 73.0%–98.9%; 16/17), in 28.4% of the mesaticephalic dogs (95% CI 20.6%–37.8%, 29/102) and in only one out of 19 dolichocephalic dogs studied (5.3%, 95% CI 1.0%–24.6%). The differences were statistically significant ($P < 0.001$) (Fig. 3).

There were no significant differences in IOW values between the constitutional types ($P = 0.865$) nor a linear correlation between the IOW and SI ($r = –0.054$, $P = 0.531$).

None of the studied parameters had any significant difference between males and females. The presence of a dorsal notch was identified for the first time in such breeds as the French Bulldog, the Fox Terrier, the Keeshond, the Standard Schnauzer, the English Bull-

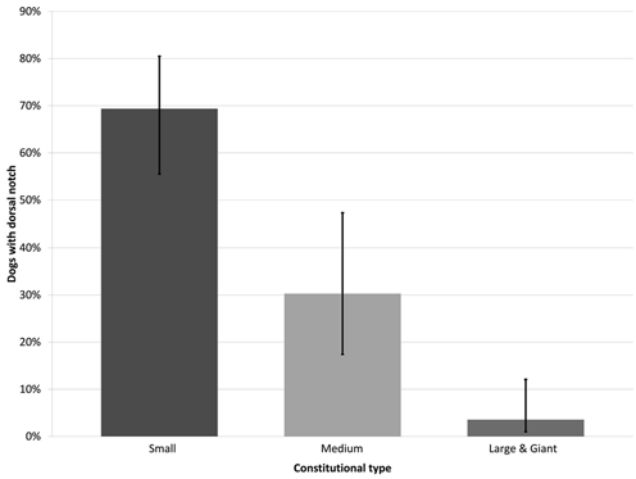

Fig. 2. Cranial index value among three different constitutional types.

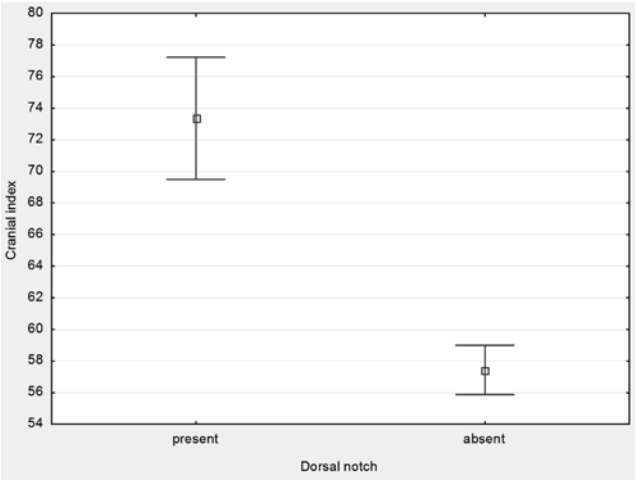

Fig. 3. Frequency of the morphotypes among three different constitutional types.

dog, the Cocker Spaniel, the Boxer and the Rottweiler (Figs 4, 5). It is interesting that the dorsal notch was present in all of the French Bulldogs included in the study (7/7, 100%).

The most frequently observed shape of the foramen magnum was the oval shape (in 41 dogs, i.e., in 45.1%, 95% CI 35.2%–55.3%), and the least often observed was the circular shape (only in 5 individuals, i.e., in 5.5%, 95% CI 2.4%–12.2%). Furthermore, the pentagonal and rhomboid shapes were almost equally represented, in 27 dogs (i.e., in 29.7%, 95% CI 21.3%–39.7%) and in 18 dogs (i.e., in 19.8%, 95% CI 12.9%–29.1%), respectively. The oval foramen magnum was the most frequently observed shape in all constitutional types but with the increasing body weight, a statistically significant trend was observed towards higher incidence of the rhomboid foramen magnum ($P = 0.003$) (Fig. 6). The round shape of the foramen magnum was observed only in the group of small breed dogs and only of the brachycephalic morphotype. The dorsal notch was found in all the cases of the round foramen magnum and it was absent in all the rhomboid foramen magnums. In the case of the oval and pentagonal shapes, the dorsal notch was observed in 41% (17/41) and 33% (9/27) of dogs respectively.

Discussion

Occipital dysplasia, described in the source literature, manifests itself by the presence of a characteristic shape of the foramen magnum, the so-called keyhole (Parker & Park 1974; de Lahunta & Glass 2009; Evans & de Lahunta 2013). This is caused by bone loss in the ventral part of the squama of the occipital bone. The main reason of the formation of a dorsal notch is considered to be incomplete ossification of the lower-medial part of the squama of the occipital bone. The aforementioned bone loss in the squama of the occipital bone is entirely built with a strong membrane of the connective tissue, which makes the foramen magnum retain its anatomical shape (Watson et al. 1989; Rusbridge & Knowler 2006).

Currently, there is a discussion among researchers whether to consider occipital dysplasia as part of the normal morphology of the occipital bone that occurs mainly in small breeds (including the Yorkshire Terrier, the Toy Poodle, the Miniature Poodle, the Shih Tzu, the Pomeranian, the Maltese, the Chihuahua, the Pekingese, the Lhasa Apso, and the Cavalier King Charles Spaniel) as well as in Beagles (Parker & Park 1974; Wright 1979; Watson et al. 1989; Simoens et al. 1994a; Rusbridge & Knowler 2006; de Lahunta & Glass 2009; Baroni et al. 2011). According to the authors of this paper, occipital dysplasia could be considered a pathology only when it resulted in an onset of symptoms, and its incidence in the population was limited.

The available source literature provides no explicit information suggesting that the presence of a dorsal notch is the cause of neurological symptoms (Watson et al. 1989; de Lahunta & Glass 2009; Onar et al. 1997). This issue has been analyzed by a number of research teams. Baroni et al. (2011) found occipital dysplasia in all 15 tested Yorkshire Terriers and in 11 out of 15 Toy Poodles. They did not report any neurological symptoms in any individuals. Although Parker & Park (1974) observed neurological symptoms in some dogs with occipital dysplasia, they found no evidence that the dorsal notch was responsible for those symptoms. The source literature describes some cases of simultaneous occurrence of occipital dysplasia and certain symptoms originating from the central nervous system. It is believed, however, that these disorders were the consequence of other co-existing pathological changes. Wielądek & Kupczyńska (2008) described a case of a Yorkshire Terrier with motor coordination disorders. The autopsy revealed the presence of a keyhole structure. In addition, distortion of the articular surfaces of the atlanto-occipital joint was observed, which, according to the authors, could be the cause of the neurological symptoms. Moreover, Rusbridge & Knowler

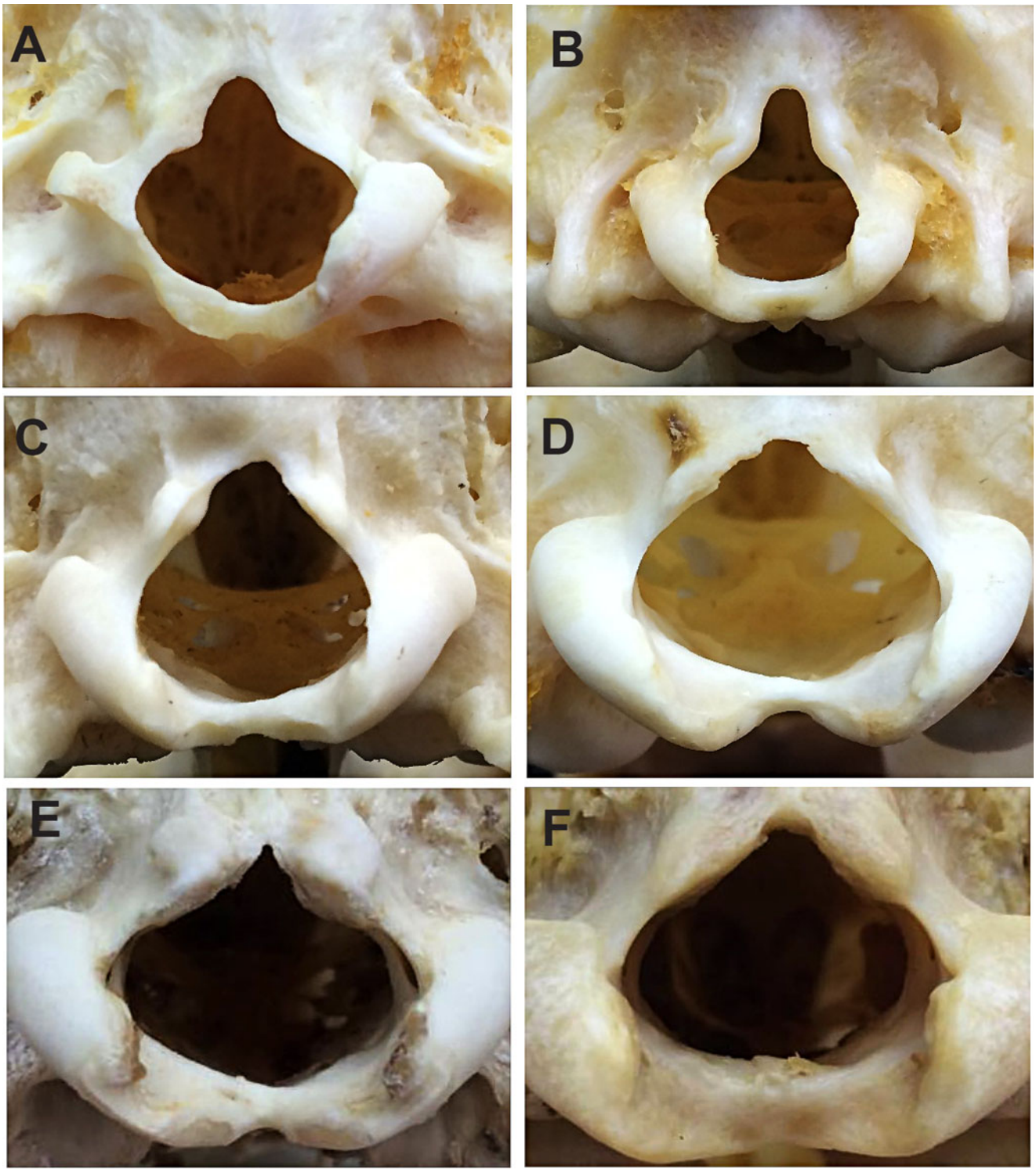

Fig. 4. Presence of the dorsal notch in: A – English Bulldog, B – French Bulldog, C – Cocker Spaniel, D – Fox Terrier, E – Boxer, F – Rottweiler.

(2006) described a case of a Cavalier King Charles Spaniel which proved to have occipital dysplasia together with occipital hypoplasia and syringomyelia. It is assumed that occipital hypoplasia which causes reduction in volume of the caudal fossa results in the cerebellar vermis protrude through the foramen magnum, cerebrospinal fluid circulation disorders and, in consequence, syringomyelia. According to the authors, the simultaneous occurrence of occipital dysplasia and occipital hypoplasia does not result in a predisposition to neurological symptoms, and may even delay the formation of syringomyelia. Most likely this is due to some "plastic" properties of the membrane covering the non ossified area of the occipital bone, which may reduce the obstruction of the flow of the cerebrospinal fluid through the foramen magnum. Nevertheless, it has to be stated here that problems concerning so called "occipital area" are most often found in Cavalier King

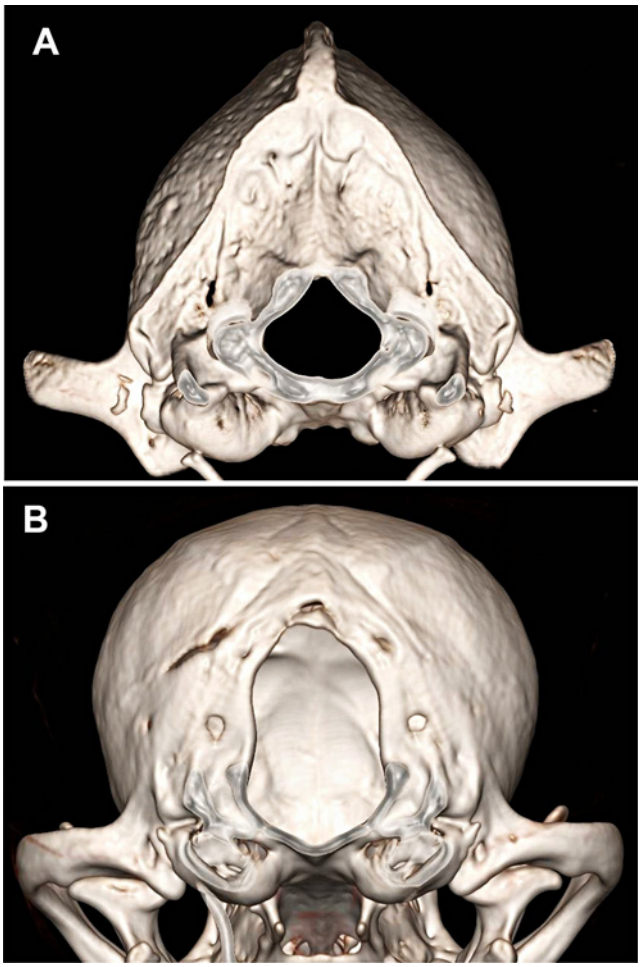

Fig. 5. Presence of the dorsal notch in: A – Standard Schnauzer, B – Keeshond.

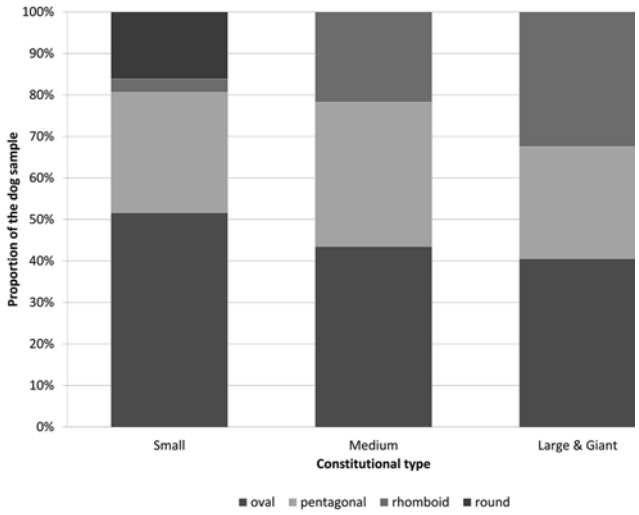

Fig. 6. Frequency of the shapes of the foramen magnum among three different constitutional types.

Charles Spaniels. Rusbridge & Knowler (2003) in their preliminary study showed what accounts for this relationship. The authors of this paper suggest that that occipital hypoplasia and secondary syringomyelia are hereditary although they state that the hereditary aspect of the disease is of variable penetrance and most likely oligogenic then simple.

When examining dog skulls from the *Byzantine times*, Onar et al. (2013) found dorsal notch in some individuals. Some of these individuals were quite old, which suggests that the presence of this morphological feature could not be the cause of their death. The research conducted by Janeczek et al. (2008) on materials from archaeological excavations confirmed the occurrence of occipital dysplasia in dogs from the Iron Age. According to the authors, again, occipital dysplasia was not the cause of the death of the studied animals.

In the study presented in this paper, the dorsal notch was observed in 33.3% of the individuals. This attribute was present in 70% of the small breed dogs and in almost 30% of the medium breed dogs. According to the data from the source literature, the foramen magnum in the shape of a keyhole is very rare in large and giant breed dogs (Simoens et al. 1994b). This is confirmed by the authors' own studies. In the group of studied dogs, it was only reported in two subjects (3.6%) – a Rottweiler and a Boxer. In contrast, Onar et al. (1997) did not find any dorsal notch in the skulls of the German Shepherd individuals, and, according to the authors, an occurrence of such a lesion in this breed should be considered as pathological. Presented study clearly show that dorsal notch most often occurred in the small sized dogs whereas in the large & giant breeds it was least observed.

The breeds, with occipital dysplasia described, are most commonly of a brachycephalic or mesaticephalic morphotype (Simoens et al. 1994b; Onar et al. 1997; Chrószcz et al. 2006; Janeczek et al. 2008, 2011; Wiełądek & Kupczyńska 2008; Baroni et al. 2011). This is confirmed by the authors' own studies which found a tendency to higher incidence of a dorsal notch in dogs with a higher cranial index (present in as many as 95% of brachycephalic dogs and about 28% of mesaticephalic dogs). Therefore, the incidence of this lesion is higher not only in small breed dogs but also in breeds with a higher cephalic index. Simoens et al. (1994b) described occipital dysplasia in 7 out of 9 Doberman Pinschers. In the author's own study, from among the dogs of the dolichocephalic morphotype and small size, the dorsal notch was described only in one Fox Terrier.

Incomplete ossification of the squama of the occipital bone is therefore often found in the modern population of dogs. Moreover, none of the studied individuals manifested any neurological symptoms. According to the authors, the presence of a dorsal notch in small and medium-sized breeds of the brachycephalic or mesaticephalic morphotype is not pathology, and should be regarded as part of the normal anatomy.

In their study, Cross et al. (2009) observed, inter alia, a group of small dogs and a group of Labrador Retrievers and proved that the average ratio of the volume of the caudal fossa to the volume of the cranial cavity is smaller in small breeds. In addition, small breed dogs have a higher percentage of *brain parenchyma* in the

caudal fossa. This means that in small breeds a certain crowding of structures may occur in the area of the caudal fossa. In the own study of the authors of this paper, the dorsal notch was found in the majority of the small breed dogs. Therefore, this crowding of structures in the area of the caudal fossa may result in compression of the cerebellum on the ossifying squama of the occipital bone and, ultimately, lead to its thinning. Such a situation has been reported in post-mortem studies in humans (Kranioti et al. 2009) and in small breed dogs, as well as in Cavalier King Charles Spaniel (Rusbridge & Knowler 2006). In order to prove the validity of this hypothesis, further studies are needed, which would take into account the correlation between the presence of a dorsal notch and the ratio of the volume between the caudal fossa and the entire cranial cavity.

As mentioned above, the studies on the morphology and morphometry of the foramen magnum were conducted in various species of domestic and wild mammals (Wąsowicz et al. 2009; Baroni et al. 2011; Yahaya et al. 2013). For obvious reasons, most of the reports describing the morphometry of the foramen magnum concern humans. This is due to a number of research on the anterior cervical junction, which, apart from morphometric observations, also include some precise descriptions of its shape (Zaidi & Dayal 1988; Chethan et al. 2012; Murshed et al. 2003; Kranioti et al. 2009; Richards & Jabbour 2009; Natsis et al. 2013; Aragao et al. 2014).

It should be emphasized that there are no unified descriptions of the shape of the said foramen. Some authors describe it as: a round shape, egg shape, tetragonal, oval, irregular, hexagonal and pentagonal (Chethan et al. 2012; Aragao et al. 2014).

Richards & Jabbour (2009), in turn, conducted a study on 470 skulls of humans of various age. They identified as many as eight categories of the foramen magnum shape: circular, two semicircles, heart-like wide oval, bi-rounded oval, ventrally wide oval, bi-pointed oval and dorsally convergent oval. It is worth noting that most of them are variances of the oval shape. The authors also observed that with age, the width of the foramen magnum tends to expand, taking the shape of a ventrally expanded oval.

Richards & Jabbour (2009) also observed a correlation between the cranial index and the diversity of the shape categories of the foramen magnum. In dolichocephalic humans, there are only oval shapes (five of the aforementioned variances) and mesaticephalic and brachycephalic humans may have any of the aforementioned shapes of the foramen magnum.

In the authors' own study, in 91 studied dogs the most often found shape of the foramen magnum was the oval one. The round shape was found in the small breeds of the brachycephalic morphotype. In the study on the nuchal plane in camels, the authors distinguished three types of the foramen magnum shape (Yahaya et al. 2013). It has to be emphasized that they assessed only its dorsal outline. In type I, it is smoothly curved and does not show any bony protrusions or notches. In type II, in the median plane of the foramen, there is a small bony protrusion in the dorsal direction. Type III is described as a foramen magnum with a dorsal notch, similar to the one described in dogs (Yahaya et al. 2013). In studies conducted by Wąsowicz et al. (2009) on 50 domestic cats, only the oval shape of the foramen magnum was found. No dorsal notch was found in any of those animals.

The only publication, which presents an analysis of the shape variation of the described structure in the dog is a publication by Baroni et al. (2011). In the examined group of 30 miniature breeds, the Toy Poodle and the Yorkshire Terrier, two shapes of the foramen magnum were observed: oval and square. The authors did not provide any guidelines for which they created the above mentioned categories. In the X-ray examinations, only in four analyzed dogs (all of them were the Toy Poodle dogs) the presence of a dorsal notch was not shown. The authors evaluated the shape of the foramen magnum excluding the dorsal notch.

Conclusions

The dorsal notch was found in 33.3% of all studied individuals, both of the small and medium-sized breeds. Out of three described morphotypes, the dorsal notch was reported in brachycephalic and mesaticephalic dogs. According to the authors, the dorsal notch does not constitute pathology and should be considered a morphological variation within the normal anatomy of the domestic dog. The most commonly reported shape of the foramen magnum was the oval shape, and the least common was the round shape. The rhomboid shape occurs more frequently with the increase of the dog's body weight. The round shape of the foramen magnum was observed only in the group of the small breed dogs and only of the brachycephalic morphotype.

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