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Research Article

Gender Determination of Foramen Magnum and Occipital Condyles in Dogs Using Computed Tomography

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Abstract

The foramen magnum (FM) and occipital condyles (OC) are important anatomical features in anthropology and zooarchaeology for the identification of breeds, species, and gender. The present study aimed to determine the gender of dogs using morphometric measurements of the FM and OC. A total of 27 healthy dogs without any pathology, 11 females and 16 males, were used in this study. Morphometric measurements were performed on tomography images of the dogs' heads. Before morphometric measurements were made on the images obtained in DICOM (Digital Imaging and Communications in Medicine) format, interactive MPR (Multi-Planar Reformat) and positioning were performed in ITK-SNAP software. After rotation and positioning, eight different morphometric measurements were performed on the FM and OC using ITK-SNAP software. According to the morphometric measurement results, no statistical difference was determined in the length of the right OC(LROC), length of the left OC (LLOC), width of the right OC (WROC), width of the left OC (WLOC), intercondylar width (ICW), intercondylar distance (ICD), and internal width of the FM (IWFM) in female and male dogs. A difference was observed in the internal length of the FM (ILFM) parameter, which was found to be statistically significantly higher in males. It is thought that the morphometric measurement results obtained from the FM and OC of dogs will contribute to zooarchaeological and anthropological studies examining the differences between gender and head structure in dogs.

Keywords: Computed tomography, dog, foramen magnum, morphometric measurement, occipital condyles

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Introduction

The bones that form the skull consist of two groups: neurocranium and viscerocranium. The viscerocranium contains the initial parts of the digestive and respiratory systems. Neurocranium, whose primary function is to protect the brain, also contains the middle and inner ear. The occipital bone, located caudally from the neurocranium bones, articulates with the atlas, the first vertebra (König et al 2004, Dyce et al 2010). The parts of the occipital bone form the foramen magnum (FM), a sizeable ring-shaped opening that connects the cranial cavity to the vertebral canal (König et al 2004, Akbaş et al 2023). The spinal cord is connected to the brain through the FM. In addition, the passage of the meninges, vertebral venous sinuses, and basilar artery make the FM very important in neurosurgical practice (Evans and De Lahunta 2012).

Anthropology, comparative anatomy, archeology, and neurosurgery are interested in the shape and anatomical features of the FM and occipital condyles (OC). It is also reported that the morphological structures of the FM and OC have changed and are of anthropological interest (Muthukumar et al 2005, Pires et al 2016, Ruth et al 2016, Law et al 2018, Aida et al 2020, Akbaş et al 2023). It is known that the FM and OC in dogs vary significantly between breeds. In most cases, the transverse diameter of the FM is larger. However, in some skulls, the width and height of the FM have been observed to be equal. Some dog breeds may have developmental disorders in this area. These disorders can cause neurological symptoms, such as parts of the brain bulging from the FM (Getty 1975, De Lahunta et al 2014, Czubaj et al 2015, Kupczyńska et al 2017). Similarly, in some dog breeds, the dorsal extension of the FM creates a dorsal notch that resembles a keyhole. This dorsal notch, defined as occipital dysplasia, is also evaluated as a morphological variation in terms

of anatomy in some cases (Wright 1979, Simoens et al 1994, Evans and De Lahunta 2012, Onar et al 2013, De Lahunta et al 2014). These irregularities observed in the shape and size of the FM are defined as malformation (De Lahunta et al 2014).

The FM is important for cerebrospinal fluid circulation, and if it becomes blocked, it may cause syringomyelia. Occipital bone hypoplasia is one of the most common causes of syringomyelia (Rusbridge et al 2000). Malformation of the basis and supraoccipital bone may cause a decrease in the volume of the caudal fossa and the spinal cord to displace dorsally, with the vermis passing through the FM (Rusbridge and Knowler 2006).

Morphometric measurements obtained from the skull are frequently used to determine gender, breed, and species dimorphism in mammals. One of the most important of these measurements is the findings obtained from the FM and OC (Onar et al 2001, Uddin et al 2013, Saber and Gummow 2015, Akbaş et al 2023, Gundemir et al 2023a, Gündemir et al 2023b, Duro et al 2025, Gündemir et al 2025, Gündemir and Szara 2025).

Different methods are used when performing morphometric measurements. In addition to the conventional measurement method using digital calipers, in recent years, measurements have also been made on computed tomography (CT) images. Morphometric measurements were performed on the skull, including measurements of the FM using digital calipers in dogs (Onar et al 2002, García-Real et al 2004, Baranowski 2010, Janeczek and Chrószcz 2011, Onar et al 2012, Saber and Gummow 2015, Bennett and Timm 2018, İlgün et al 2022, Güzel et al 2023, Koçyiğit and Demircioğlu 2024, Koçyiğit et al 2024a, Koçyiğit et al 2024b). In recent years, in addition to these methods, morphometric measurements are also being performed on 3D models obtained using computed tomography images (Bakıcı et al 2022, Selcuk 2023).

There are also measurements focusing directly on the FM and the occipital region in dogs (Janeczek et al 2008, Onar et al 2013, Kilroy and Kumar 2015, Kupczyńska et al 2017). Morphometric measurements were performed on the FM and OC in American Staffordshire Terriers (Chrószcz et al 2006, Janeczek et al 2011), Nigerian local breed (Igado and Ekeolu 2014, Danmaigoro and Mahmud 2022), Cavalier King Charles spaniels (Schmidt et al 2012), small and toy breeds (Baroni et al 2011, de Sousa Júnior et al 2022), Pekingese (Simoens et al 1994), German Shepherd (Onar et al 1997), Kangal (Onar et al 2001), Ghanaian local dog (Opoku-Agyemang et al 2020) and Egyptian Baladi (Mahdy and Mohamed 2022).

More detailed measurements are made using CT compared to conventional morphometric measurements made with digital calipers. The motivation for the study is that information on morphometric measurements in the FM and OC using CT in dogs is limited. The study aims to perform morphometric measurements in the FM and OC in dogs using CT. Additionally, the relationship between age and weight with morphometric measurements obtained from FM and OC was examined.

Material and Methods

Study Population

A total of 27 healthy dogs (mesaticephalic and dolichocephalic), 11 female and 16 male, were used in the study. The female dogs aged from 1 to 13 years (mean age 6.18 years), and male dogs from 1 to 13 years (mean age 7.44 years) were used in the study. The average weight of female dogs was 19.55 kg, and that of male dogs was 25.25 kg. CT images of dogs without any pathological condition were obtained from archive images, the Animal Hospital of the Faculty of Veterinary Medicine, Istanbul University-Cerrahpaşa. The dogs' heads were scanned in recumbency using a multi-detector Siemens (Somatom Scope vc30b) CT device. CT images of dog heads with 110 kV, 28 mA, and 0.6 mm slice thickness were obtained. Images stored in DICOM (Digital Imaging and Communications in Medicine) format were transferred to open-source ITK-SNAP software (Yushkevich et al 2006). Morphometric measurements of the FM and OC were performed using ITK-SNAP software.

Morphometric Measurements of FM and OC

Morphometric measurements of the FM and OC were performed using CT images. CT images were positioned with interactive MPR before linear measurements were performed (Figure 1).

The morphometric measurements shown in Figure 2 and mentioned below were performed (Simoens et al 1994, Onar et al 1997, Onar et al 2001, Chrószcz et al 2006, Janeczek et al 2008, Baroni et al 2011, Janeczek et al 2011, Schmidt et al 2012, Onar et al 2013, Igado and Ekeolu 2014, Kilroy and Kumar 2015, Kupczyńska et al 2017, Opoku-Agyemang et al 2020, Ramos et al 2021, Danmaigoro and Mahmud 2022, de Sousa Júnior et al 2022, Mahdy and Mohamed 2022, Akbaş et al 2023, Gundemir et al 2023a).

LROC: Length of the right OC; LLOC: Length of the left OC; WROC: Width of the right OC; WLOC: Width of the left OC; ICW: Intercondylar width; ICD: Intercondylar distance; ILFM: Internal length of the FM; IWFM: Internal width of the FM.

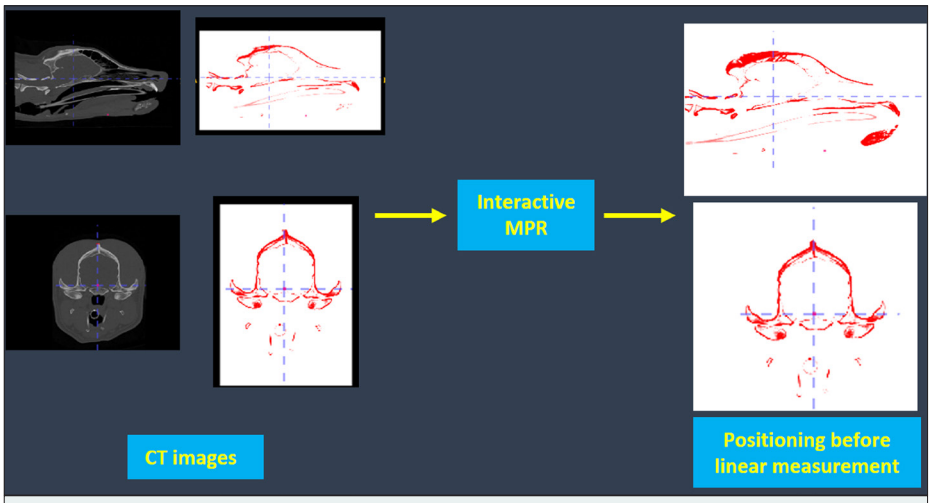

Figure 1. Rotation before linear measurements is performed.

In addition, the FM index (FMI) was calculated according to the following equation: FMI= (MWFM/MLFM)*100

Statistical analysis

Statistical analysis was performed using the software SPSS 29 statistics software. Homogeneity and normality of variances were tested using Levene's test and Shapiro-Wilk. In a gender comparison, the Student's t-test was used in cases where parametric test prerequisites were met, and the Mann–Whitney U test was used in cases where they were not met. The relation between measurements obtained from the FM and OC was examined using Pearson's correlation.

Results

Morphometric measurements were performed using CT images obtained from female and male dogs. Morphometric measurements and FMI obtained from the FM and OC in dogs are presented in Table 1.

Eight different morphometric measurements and an index calculation were performed on the FM and OC. In all measurements obtained, the average values from males were higher. A statistical difference was observed in the ILFM value. It was determined that this measurement parameter was higher in males. In other measurements, no statistical difference was found between male and female dogs. It was observed that the FM index was higher in female cats, but it did not create a statistical difference.

The correlation between the morphometric measurements obtained from the dog the FM and OC is presented in Table 2. In the correlation between morphometric measurements, moderate, strong, and very strong relationships were taken into account. The relationship between age and weight on measurements was investigated.

The highest correlation with age and morphometric measurements was observed with WROC and WLOC. However, no statistical difference was observed between

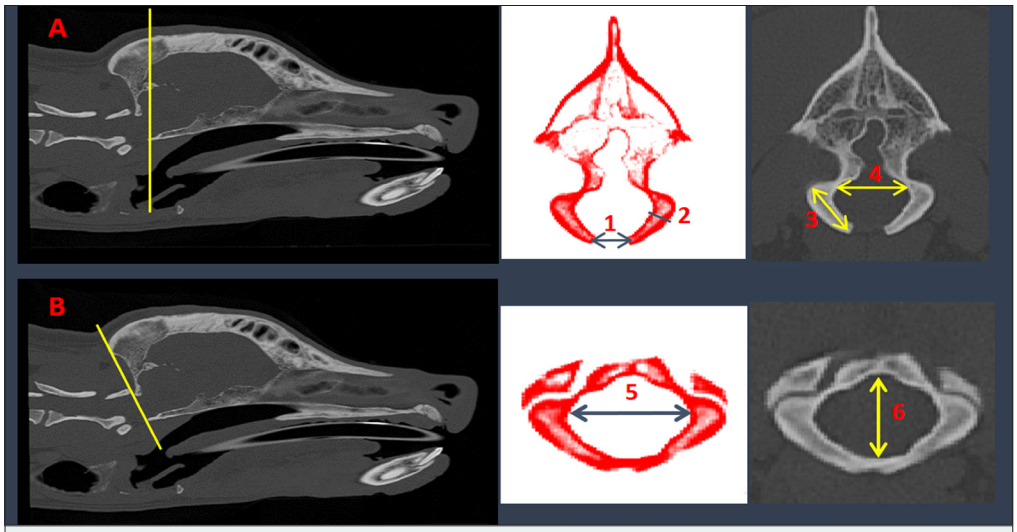

Figure 2. Measurements performed at the OC (A) and FM (B). Intercondylar distance (1); Width of the left OC (2); Length of the right OC (3); Intercondylar width (4); Internal width of the FM (5); Internal length of the FM (6).

Table 1. Morphometric measurements obtained from the FM and OC							
	Female (n=11)			Male (n=16)			
Measurements	Min	Max	Mean ± SD	Min	Max	Mean ± SD	
LROC	10.37	17.23	14.25±2.17	11.81	19.78	15.73±2.79	0.155[£]
LLOC	10.08	17.43	14.13±2.36	12.33	18.84	15.63±2.38	0.118[£]
WROC	4.14	6.76	5.52±0.87	4.01	8.22	5.93±1.34	0.392[£]
WLOC	4.14	6.75	5.57±0.84	3.92	8.56	6.16±1.59	0.277[£]
ICW	13.96	19.41	16.46±2.15	14.27	21.04	17.45±2.07	0.245[£]
ICD	7.21	13.93	10.26±1.97	8.83	13.98	11.41±1.55	0.105[£]
ILFM	11.25	15.39	13.74±1.35	13.44	16.81	14.82±1.06	0.027[£*]
IWFM	14.74	20.98	17.75±1.71	15.48	21.56	18.62±1.88	0.233[£]
FMI	117.38	144.69	129.53±9.01	110.49	145.48	125.60±8.84	0.270[£]

[£]Student's t-test, * p<0.05. LROC, Length of the right OC; LLOC, Length of the left OC; WROC; Width of the right OC; WLOC, Width of the left OC; ICW, Intercondylar width; ICD, Intercondylar distance; ILFM, Internal length of the FM; IWFM, Internal width of the FM; FMI, FM index.

age and the measurements. A positive correlation was found between weight and all morphometric measurements. The highest correlation between weight and measurements was determined in IWFM. The lowest correlation between weight and morphometric measurements was observed in ICD. A positive correlation was observed between all morphometric measurements obtained from the FM and OC in dogs. The highest correlation was determined to be in the maximum length and width obtained from the OC.

Discussion

The FM is important in veterinary clinical practice, forensic medicine, species identification, and gender determination (König et al 2004, Akbaş et al 2023). Non-invasive studies using imaging techniques prevent the need for animal sacrifice. CT is an important and frequently used technique that provides the most reliable and accurate results (Akbaş et al 2023).

Due to the variations observed in anatomy, and morphological features of the FM, it is particularly studied in the fields of anatomy, anthropology, and zooarchaeology. The size and shape of the FM in dogs vary considerably depending on head structure (Muthukumar et al 2005, Pires et al 2016, Ruth et al 2016, Law et al 2018, Aida et al 2020, Akbaş et al 2023).

In our study, the morphometric parameters of the FM and OC were evaluated in dogs. In most cases in dogs, the IWFM value is higher than the ILFM. In most dogs, the IWFM value is greater than the ILFM. In dogs with a dorsal notch, the ILFM value is higher (Getty 1975, Wright 1979,

Table 2. Correlations between morphometric measurements and age/weight.											
	Age	Weight	LROC	LLOC	WROC	WLOC	ICW	ICD	ILFM	IWFM	FMI
Age	1										
Weight	0.396	1									
LROC	0.113	0.625**	1								
LLOC	0.159	0.649**	0.964**	1							
WROC	0.255	0.738**	0.887**	0.879**	1						
WLOC	0.255	0.733**	0.905**	0.894**	0.964**	1					
ICW	0.064	0.624**	0.771**	0.803**	0.770**	0.792**	1				
ICD	0.133	0.579*	0.773**	0.799**	0.798**	0.741**	0.739**	1			
ILFM	0.231	0.643**	0.713**	0.753**	0.675**	0.672**	0.734**	0.634**	1		
IWFM	0.102	0.745**	0.837**	0.839**	0.838**	0.801**	0.844**	0.740**	0.724**	1	
FMI	-0.145	0.241	0.279	0.231	0.324	0.278	0.260	0.241	-0.246	0.489	1

*p<0.05, **p < 0.01. LROC, Length of the right OC; LLOC, Length of the left OC; WROC; Width of the right OC; WLOC, Width of the left OC; ICW, Intercondylar width; ICD, Intercondylar distance; ILFM, Internal length of the FM; IWFM, Internal width of the FM; FMI, FM index.

Simoens et al 1994, Evans and De Lahunta 2013, Onar et al 2013, De Lahunta et al 2014, Czubaj et al 2015, Kupczyńska et al 2017). In a study using mesaticephalic dogs, the IWFM value was found to be higher in both males and females when the dorsal notch was not present in the materials used. Similarly, IWFM was found to be higher in cats. A gender difference was observed in IWFM and ILFM (Uddin et al 2013, Ramos et al 2021, Akbaş et al 2023). However, in mesaticephalic dogs, a gender difference was found only in ILFM (p=0.027). This value was observed to be higher in male dogs.

Morphometric measurements of bones are made using various methods (Onar et al 2001, Uddin et al 2013, Duro et al 2025, Gündemir et al 2025, Gündemir and Szara 2025). Conventional measurement methods using digital calipers are often preferred. However, in recent years, X-ray and CT images have also been used in morphometric measurements (Onar et al 2002, García-Real et al 2004, Baranowski 2010, Janeczek and Chrószcz 2011, Onar et al 2012, Saber and Gummow 2015, Bennett and Timm 2018, İlgün et al 2022, Güzel et al 2023, Koçyiğit and Demircioğlu 2024, Koçyiğit et al 2024a). Measurements made using digital calipers are very important in measuring skulls from archaeological excavations. FM measurements were taken on dog skulls found during the Van-Yoncatepe Necropolis excavations, as well as on skulls from the Iron Age, early medieval, and medieval periods. Similar to the present study, the IWFM value was measured as higher than the ILFM in the dog skulls found in the Van-Yoncatepe Necropolises excavations Iron Age, and medieval dogs. The FMI calculated in both studies was observed to be lower than the value calculated in the current study. This difference is thought to be due to the skulls found in the archaeological excavations belonging to dogs of different breeds and with different head lengths (Onar et al 2002, Janeczek et al 2008, Baranowski 2010, Janeczek and Chrószcz 2011). IWFM values in early medieval short-snout and medium-snout dogs were found to be consistent with the present findings. It was stated that the values of LROC and LLOC were higher in short-snout dogs (Baranowski 2010). The values obtained from the ILFM and IWFM measurements in the FM of Byzantine dolichocephalic and mesaticephalic dogs were found to be very close to the present study (Onar et al 2013). In the measurements made using digital caliper from the FM in Aksaray Malakli, the ILFM value was determined to be higher than the IWFM. In the current study, IWFM values were measured higher in both female and male dogs (İlgün et al 2022). This difference is thought to be because no dorsal notch was found in the dogs measured in the study, but a dorsal notch was observed in the skull of Aksaray Malakli. Morphotypes of the FM were studied in different breeds of dogs with constitutional types of small, medium, large, and giant. In the study investigating the presence of the dorsal notch, it was stated that the dorsal notch was less frequently encountered in the medium-sized breed dog group. The presence of a dorsal notch was not observed in the dogs used in the present study.

Similar to the present study, higher IWFM values were found in morphometric measurements of FM in American Staffordshire Terriers, Nigerian local breed, small and toy breeds, Pekingese, German Shepherd, Ghanaian local dog and Egyptian Baladi (Onar et al 1997, Baroni et al 2011, Janeczek et al 2011, Igado and Ekeolu 2014, Opoku-Agyemang et al 2020, Danmaigoro and Mahmud 2022, Mahdy and Mohamed 2022). ILFM and IWFM values were compared in terms of gender in Aksaray Malakli, Nigerian Local, and German Shepherd. While no difference was observed in Aksaray Malakli and German Shepherds, a difference in IWFM was observed in Nigerian local dogs. This value was observed to be higher in female Nigerian local dogs (Onar et al 1997, Igado and Ekeolu 2014). In the current study, a difference in ILFM was observed, and it was measured higher in males. In addition to measurements made directly on the FM of dog skulls using digital calipers, measurements were also made on X-ray and CT, similar to the present study (Baroni et al 2011, Güzel et al 2023).

The use of certain head structures (mesaticephalic and dolichocephalic) breeds in the current study and the possible effects on cranial morphology constitute the limitation of the study. Future studies directly involving specific breeds are expected to provide more specific data and contribute significantly to the literature in this field.

Conclusion

Morphometric examination of the FM and OC, two important structures of the skull, was performed using CT. The FM plays an important role in comparative anatomy, anthropology, and surgery due to its shape and anatomical features. Eight different morphometric measurements and an index calculation were performed in dogs using CT. In the morphometric measurements, a difference was observed in terms of gender in ILFM (Internal length of the FM). It is thought that the findings obtained in the present study can be compared with findings obtained from dogs with different cranial constitutional types and can be used in the identification of dog skulls found in archaeological excavations.

Declarations

Competing Interests

Authors declares that there are no conflicts of interest related to the publication of this article.

Availability of Data and Materials
The data that support the findings of this study are available on request from the corresponding author.

Ethical Statement
Istanbul University-Cerrahpasa Research and Application Center, Animal Experiments Ethics Committee 05.09.2025, 2025/81 Number Ethics Committee Decision.

Author Contributions
Motivation/Concept: SA; Design: YA; Control/Supervision: SA; Data Collection and Processing: YA, MTT; Analysis and Interpretation: SA, YA, MTT; Literature Review: SA; Writing the Article: SA, YA; Critical Review: SA

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