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ARAŞTIRMA / RESEARCH

Harmony of the foramen magnum and cranium: An anatomical and radiological study

Foramen magnum ve kranyumun uyumu: Anatomik ve radyolojik bir çalışma

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Abstract

Purpose: The measurements' reference points associated with foramen magnum (FM) and cranium were examined in this retrospective study. Also, the relation between FM and cranium harmony were calculated both on dry skull and in healthy subjects performed on computed tomography (CT).
Materials and Methods: The present study was carried out on 185 healthy adult subjects (90 females; 95 males) aged between 18–67 years and 15 dried skull of unknown gender of an Anatolian population. The shapes of the FM were classified as two semicircle, oval, round, egg, tetragonal, pentagonal, hexagonal and irregular shapes. The anteroposterior length and transverse width of the FM and cranium were measured on both photos and CT.
Results: The means and standard deviations of the measurements were given for three groups. To control the accuracy of FM width (FMW) and length (FML) results, a formula was used for three groups including dried skull and CT measurements of females and males, seperately (FMW=Cranial width (CW)/4.26 for group 1, CW/4.66 for group 2 and CW/4.66 for group 3; and FML=Cranial length (CL)/4.51 for group 1, CL/4.33 for group 2 and CL/4.16 for group 3). The oval type FM was predominant (26.67%) in dried skull and (23.33%) in females and (28.42%) in males.
Conclusion: The present study presents noteworthy data about FM and cranium harmony of the adult Turkish population and dry skulls that will show a harmony between cranium and foramen magnum in clinical practice. There was no tetragonal and hexagonal FM types in dried skulls and tetragonal type FM was the least seen type in females and males.
Keywords:. Foramen magnum, age and gender related changes, morphometry, shapes, cranium harmony

Öz

Amaç: Bu retrospektif çalışmada, foramen magnum (FM) ve kranyum ile ilişkili ölçümlerin referans noktalarını incelendi. Ayrıca, FM ve kafatası harmonisi hem kuru kemik üzerinde hem de Bilgisayarlı Tomografi (BT) kullanılarak sağlıklı kişilerde hesaplandı.
Gereç ve Yöntem: Mevcut çalışma, yaşları 18-67 yaş arası değişen Türk popülasyonuna ait 185 sağlıklı yetişkin (90 kadın; 95 erkek) ve cinsiyeti belli olmayan yetişkin Anadolu insanına ait 15 kuru kafatası kullanılarak gerçekleştirildi. FM şekilleri iki yarım daire, oval, yuvarlak, yumurta, dörtgen, beşgen, altıgen ve düzensiz olarak sınıflandırıldı. FM ve kranyum ön-arka uzunluğu ve transvers genişliği hem fotograf hemde BT üzerinde ölçüldü.
Bulgular: Ölçümlerin ortalama ve standard sapmaları üç grup için verildi. FM genişliği (FMG) ve ön arka uzunluğu (FMU) ölçüm sonuçlarının doğruluğunu kontrol etmek için üç ayrı gruba, bir formül uygulandı (FMG=kranyal genişlik/4,26; grup 1, kuru kafatası için; kranyal genişlik/4,66; grup 2, erkekler için BT ölçümleri; kranyal genişlik/4,66; grup 3, kadınlar için BT ölçümleri ve FMU=Kranial uzunluk (KU)/4,51; Grup 1; KU/4,33; Grup 2 için ve KU/4,16; Grup 3 için). Oval tip FM, kuru kafatasında (%26,67), kadın (%23,33) ve erkek (%28,42) BT'de en yaygın görülen şekildi.
Sonuç: Mevcut çalışma yetişkin Türk popülasyona ve kuru kafatasına ait FM ve kranyum harmonisi ile ilgili klinik uygulamalarda kullanılmak üzere FM ve kranyum arasındaki harmoniyi gösterecek kaydadeğer bir veri sunmaktadır. Dörtgen ve altıgen şekilli FM'ye, kuru kafatasında rastlanılmazken, tetragonal tip FM hem kadın hem de erkeklerde en az karşılaşılan tip FM'ydi.

Anahtar kelimeler: Foramen magnum, yaşa ve cinsiyete bağlı değişimler, morfometri, şekiller, kranyum harmonisi

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INTRODUCTION

The occipital bone is located at the posterior part of the basis cranii. The one of the most remarkable features of occipital bone is the existence of a big hole namely foramen magnum (FM). It consists anatomically four parts surrounding the FM as the basilar, squamous, and two condylar parts[1-3]. The FM is both a crucial reference point and has a vital importance because of seeing the vertebral artery and lower cranial nerves directly[2,4]. Also, the importance is based on FM'close relation with the brainstem and spinal cord, an enlargement of the medulla oblongata[2,4]. The FM is a critical structure and clinically relevant revealing many pathologies, planning surgery and evaluation for radiologist, neurosurgeons, anaesthetist and anatomist[2,4-9]. Additionally, the FM types, FM morphometry and variations are required for accurate diagnosis and treatment[2,4].

Several anatomic proportions such as the shape, size of the FM should be taken into consideration during surgery concerning the posterior and lateral craniovertebral junction[4]. In addition, the morphometric analyses of FM including length and width are used in patients with achondroplasia and in forensic medicine abot sex determination. Moreover, cervicomedullary compression may develop as a result of FM stenosis, resulting in neurologic findings[10]. In Degno et al.'study, it is reported that the longer FM length allows greater contralateral surgical approaches about condylar resection. Partial resection of the occipital condyle in transcondylar surgery is a valuable stage for access to the ventral and ventrolateral part of FM. In other words, the FM morphometry may be benefit for lateral surgical approaches for reaching lesions in the middle and posterior part of cranial base[11,12]. Furthermore, the knowledge of FM shape and anatomic variations may affect some surgical procedures including vertebral artery, posterior inferior cerebellar artery aneurysm repairs, FM meningioma resections, and FM decompression[2,4-9]. The data also provide the valuable information about neurologic interpretation and play an important role in diagnostic, clinical and radiological aspects[2,4,7].

The FM shapes were evaluted according to FM type classification by various researchers. The shapes of FM differ from; it can be two semicircles oval, egg, round, tetragonal, pentagonal, hexagonal, and irregular[2,4,9,11,13-16]. The variations in the FM types may be affected some factors like various ethnical group, sample size, sexual dimorphism and types of population[9]. Also, the FM morphometry may be different from population because of genetic, environment and socio-economic factors[13].

In briefly, in early fetal development, FM is the one of the centres of ossification and its shapes are variable because of evolutionary changes. The irregular shape of the FM might be a reason for developmental anomalies related to bones and soft tissues at the craniovertebral junction[9,13]. Because of the probability of the relationship presence between FM and cranial morphometry and morphology, the present study were planned. There is not enough study analyzed relation with cranial and FM harmony. The obtained data can be important for both in terms of revealing the variations and size of the FM and the existence of harmony between cranium and FM in Turkish population both dried skulls and CT. So, we examined whether there is a relation between FM and cranium or harmony existence between FM and cranium dimensions or not, both in 15 dried skulls and 185 CT images.

The hypothesis of this study is that are there any relation between FM dimensions and age/gender. Also, can a harmony be detemined between FM and cranium.

MATERIALS AND METHODS

Subject and study design

The present study was carried out both on 185 healthy adult subjects (90 females; 95 males) aged 18–67 years 2018 and 2022 and 15 dried skull. All CT scans were obtained using a 128 slice multidetector CT (Siemens Somatom Definition AS, Siemens Healthcare). GPower software (version 3.1.9.7) was used to determine sample size [17]. The data were divided into three groups: dried skulls, healthy adult female and male subjects (Tables 1-3). Furthermore, the CT data were divided also into six groups according to age:

Subjects are grouped as ;

- 18 and 20 years were assigned as group 1
- 21–30 years, group 2
- 31–40 years, group 3
- 41–50 years, group 4
- 51–60 years, group 5

61-67 years, group 6 (Table 4).

The measurements were made on the computer screen with an electronic calliper and estimations were expressed as centimeter. Also, this study was a retrospective observational study which performed in Department of Radiology at Bozyaka Education and Research Hospital in İzmir. CT Image analyses were performed by two observers [observer 1, a radiologist (MO) and observer 2, an anatomist (SP)]. Additionally, the four observers reviewed and decided FM shapes both on CT images and dried skulls. Also, the measurements of 15 dry skulls (the exact age and sex of the skulls have not been determined) of human adults from the Anatolian population were performed by two observers (DV and SP). The dry skulls were ideally placed under constant light. DSLR camera (Canon EOS 80D) settings were fixed at ISO 100 f/4.5 exposure 1/25 and photos were taken. Scaling paper of known size was used as a scale for each shot. After the images were transferred to the computer environment, reference points were marked and FM and cranial measurements performed.

This study has been approved by the Cukurova University, Clinical Researches Ethics Committee, with Decision No:2022/122-48.

Data collection tools

Adult subjects were selected by criteria of optimal health. Exclusion criteria were;

1) history of receiving a diagnosis of cancer or a tumoural mass
2) Any neurologic disease
3) Having surgical operation related to medulla spinalis and brain stem (especially medulla oblangata/pons)
4) A pathology involved in FM.
5) Partially fragmented and broken and unclear bones having unclear reference landmarks (for dried skulls).

The landmarks used in this study were as follows[2,4,9,13] (Figure 2).

The anteroposterior diameter of FM (FML) was measured from the end of the anterior border (basion) to the end of the posterior border (opisthion).

The transverse diameter of FM (FMW) was measured from the point of maximum concave on the right edge to the maximum concave on the left edge (Fig. 2).

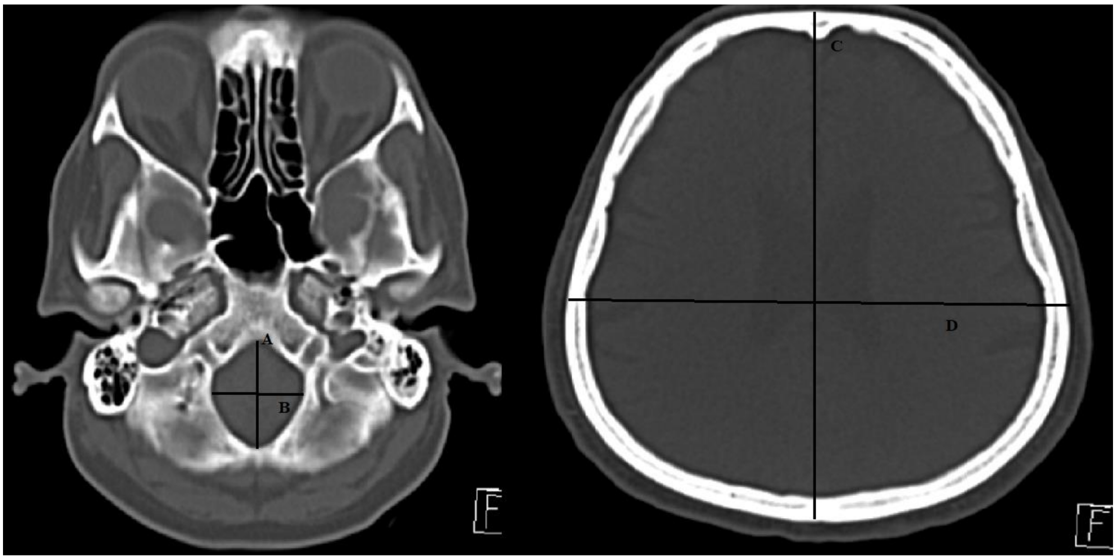

Figure 1. Evaluation of linear measurements on CT images
A: Foramen magnum length; FML, B:Foramen magnum width; FMW, C:Cranium length; CL, D: CW;Cranium width

The length of the skull (CL) was estimated as the distance between the glabella and opisthocranion. The skull width (CW) was measured between the two most remote points (eurion-eurion) located on the right and the left side of the skull (eu-eu) (Fig. 1). The cranial index (CI) (CW/CL×100) and FM index (FMI) (FMW/FML×100) were calculated. Also, the FM shapes were classified as two semicircle, oval, round, egg, tetragonal, pentagonal, hexagonal and irregular shapes and showed in Fig. 2.

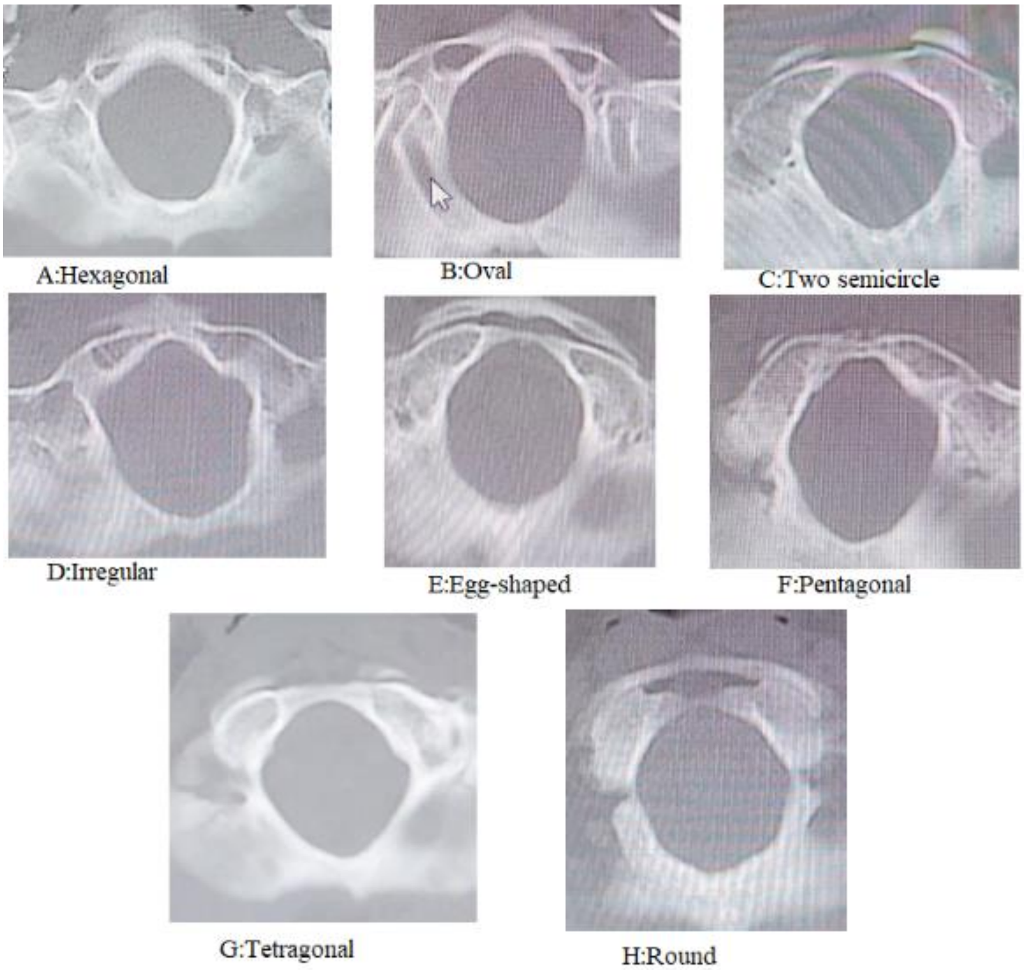

Figure 2. Foramen magnum shapes on CT

In this study, a new formula that was previously and firstly used in a study performed by Ulcay et al.[2], was applied. The mean of the coefficients of the CW to FM width ratio (CW-FMW) and the CL length to FM length (CL-FML) index were used. The values results from these indexes recorded. Based on this ratio, the coefficients were found for three groups separately and obtained a prediction value for FMW and FML (FMW=CW/**4.26** for group 1, CW/**4.66** for group 2 and CW/**4.66** for group 3). To look the accuracy of FMW and FML measurement results, the formula was made (FML=CL/**4.51** for group 1, CL/**4.33** for group 2 and CL/**4.16** for group 3). In other words, it was estimated observed and prediction FMW and FML values with the coefficient from these ratios and the significance was calculated. So, the aim is to reveal whether is there any consistence between each other.

Statistical analysis

Statistical analysis of the study data was performed using Statistical Package for the Social Sciences (SPSS) version 21.0 software for Windows. Normality assumption was decided to Shapiro Wilk test. From these measurements, means, standard deviations (SD), minimum (min.) and maximum (max.) values were calculated. In all statistical analyses; p value under 0.05 was considered to be statistically significant. According to Shapiro Wilk test result, ANOVA and Paired Sample T test were used to the comparison of the three groups in the study. FM shapes comparison was made with Chi Square test. Also, GPower software (version 3.1.9.7) was used to determine sample size[17].

RESULTS

The FML and FMW, CL and CW of three groups (group 1, 15 dried skulls, and 185 CT (group 2, 95 males, group 3, 90 females) were measured. According to results we calculated CI (CW/CLx100) and FMI (FMW/FMLx100). The descriptive values of CW, CL, CW/FMW, CL/FML, FMW and FML prediction and observed values, FMI, Index-1 (FMW/CW)*100, Index-2 (FML/CL)*100 and Index-1/Index-2 values and comparisons of groups were showed in Table 1. Also, the ratio of CW to FMW was found to be 4.66 in males, 4.66 in females, and 4.26 in dried skulls. Additionally, the ratio of CL to FML was found to be 4.33 in males, 4.16 in females and 4.51 in dried skulls (Tables 1 and 2).

To control the accuracy of FMW and FML measurement results, the formula was used (FMW=CW/4.26 for group 1, CW/4.66 for group 2 and CW/4.66 for group 3) and the other formula was made (FML=CL/4.51 for group 1, CL/4.33 for group 2 and CL/4.16 for group 3). According to these measurements, we obtained prediction value for FMW and FML. In group 1, the mean value of FM observed and prediction width were found as 2.99±0.39cm and 2.96±0.15cm, respectively (p=0.785). Also, the FM observed and prediction values were calculated as 3.31±0.46 cm and 3.27±0.31 cm in group 2 (p=0.535), 3.28±0.49 cm and 3.21±0.38 cm in group 3 (p=0.138). There was no statistically significant difference between FML observed and prediction values in three groups (means, 3.34±0.25-3.32±0.17 and p=0.787; group 1: means, 3.68±0.51-3.62±0.41 and p=0.363; group 2: means, 3.70±0.44-3.66±0.43 and p=0.545: group 3). When we investigated the FM observed and prediction width and length values, we found no significant difference between all groups (Tables 1,2). These findings show the harmony between cranium and FM. Additionally, when we compared the Index 1/Index 2, these ratios were calculated as 0.87±0.08 in group 1; 0.90±0.15 in group 2 and 0.90±0.10 in group 3, respectively. These ratios are almost equal each other (especially in females and males).

Also, when we compared the means of the FML, FMW, CL, CW, CI and FMI values performed on CT with gender, p values were found to be 0.755, 0.684, 0.027, 0.289, 0.498 and 0.196, respectively. While FML and CI values were higher in females than males, FMW, CW, CL and FMI were lower in females than in males. In Table 4, age related changes of FML, FMW and FMI on CT measurements were investigated. According to these Poct Hoc test results, the significant difference was found between decade 1 and decade 6 (p=0.045); decade 2 and decade 6 (p<0.001); decade 3 and decade 6 (p=0.029); decade 4 and decade 6 (p=0.030); and decade 5 and decade 6 (p=0.001) in FML values. The FMW values showed that there was significant difference between six decades (p=0.040). The difference was clearer between decades 2 and 4 and 6. Also, the significant difference was no found in FMI values according to age (p=0.138). Additionally, the maximum value of FML was seen in decades 2 and the minimum value was in decades 6.

In FMW measurements, the maximum value was obtained in decades 2 and the minimum value was in decades 6. The highest and lowest values of FMI were in decades 6 and 4, respectively. On the other hand, the FM shapes number and frequency of CT and dried skulls were shown in Table 3 and the FM shape images were given in Figure 3. According to results, the most frequent type was oval (26.67%) in dried skulls and (28.42%) in males and (23.33%) in females. The least frequent type was tetragonal for CT findings of both females (2.22%) and males (3.16%). Additionally, tetragonal and hexagonal shapes were no seen in dried cranium.

Table 1. Descriptive statistics of variables and groups

Variables		Mean±SD	95% CI (Lower-Upper)	P values
CW	Group 1 (15)	12.60±0.64	12.25-12.96	<0.001
	Group 2 (95)	15.22±1.42	14.93-15.51	
	Group 3 (90)	14.97±1.76	14.60-15.34	
CL	Group 1 (15)	14.96±0.76	14.54-15.38	0.042
	Group 2 (95)	15.71±1.84	15.44-16.35	
	Group 3 (90)	15.16±1.48	15.13-15.82	
CI (CW/CL)*100	Group 1 (15)	84.38±5.11	81.55-87.20	0.03
	Group 2 (95)	98.37±15.69	85.17-101.57	
	Group 3 (90)	100.06±18.12	96.26-103.86	
CW/FMW	Group 1 (15)	4.26±0.50	3.99-4.53	0.106
	Group 2 (95)	4.66±0.59	4.54-4.78	
	Group 3 (90)	4.66±0.99	4.46-4.87	
CL/FML	Group 1 (15)	4.51±0.36	4.30-4.71	0.044
	Group 2 (95)	4.33±0.61	4.21-4.45	
	Group 3 (90)	4.16±0.63	4.02-4.29	
FMW (observed)	Group 1 (15)	2.99±0.39	2.78-3.21	0.055
	Group 2 (95)	3.31±0.46	3.21-3.40	
	Group 3 (90)	3.28±0.49	3.18-3.38	
FMW (prediction)	Group 1 (15)	2.96±0.15	2.88-3.04	0.007
	Group 2 (95)	3.27±0.31	3.20-3.33	
	Group 3 (90)	3.21±0.38	3.13-3.29	
FML (observed)	Group 1 (15)	3.34±0.25	3.19-3.48	0.019
	Group 2 (95)	3.68±0.51	3.57-3.78	
	Group 3 (90)	3.70±0.44	3.61-3.79	
FML (prediction)	Group 1 (15)	3.32±0.17	3.22-3.41	0.002
	Group 2 (95)	3.62±0.41	3.53-3.70	
	Group 3 (90)	3.66±0.43	3.67-3.85	
FMI (FM width/FM length)*100	Group 1 (15)	90.48±15.63	81.82-99.13	0.442
	Group 2 (52)	90.98±14.02	88.12-93.84	
	Group 3 (41)	88.70±9.31	86.75-90.65	
Index-1 (FMW/CW*100)	Group 1 (15)	20.53±3.51	18.59-22.48	0.048
	Group 2 (95)	20.92±3.84	20.13-21.70	
	Group 3 (90)	22.23±4.07	21.38-23.09	
Index-2 FML/CL*100	Group 1 (15)	23.55±2.67	22.07±25.02	0.105
	Group 2 (95)	23.46±3.68	22.71±24.21	
	Group 3 (90)	24.65±4.24	23.76±25.53	
Index-1/Index-2	Group 1 (15)	0.87±0.08	0.83-0.92	0.577
	Group 2 (95)	0.90±0.15	0.87-0.93	
	Group 3 (90)	0.90±0.10	0.89-0.92	

SD: Standard deviations; CI: Confidence interval; CW: Cranial width; CL:Cranial length; CI:Cranial index; FMW:Foramen magnum width; FML:Foramen magnum length; FMI: Foramen magnum index; p value:significance level

Table 2. Foramen magnum descriptive statistics of three groups

Variables		Mean±SD (observed)	Mean±SD (prediction)	P values
FMW	Group 1 (15)	2.99±0.39	2.96±0.15	0.785
	Group 2 (95)	3.31±0.46	3.27±0.31	0.535
	Group 3 (90)	3.28±0.49	3.21±0.38	0.138
FML	Group 1 (15)	3.34±0.25	3.32±0.17	0.787
	Group 2 (95)	3.68±0.51	3.62±0.41	0.363
	Group 3 (90)	3.70±0.44	3.66±0.43	0.545

FMW; Foramen magnum width, FML; Foramen magnum length, p value: significance level

Table 3. The Foramen magnum shapes, number and frequency

Classification of the FM shapes	Dried skulls	FM shapes of females	FM shapes of males
Oval	4 (26.67%)	21 (23.33%)	27 (28.42%)
Egg	3 (20.00%)	18 (20.00%)	13 (13.68%)
Two semicircle	2 (13.33%)	15 (16.67%)	14 (14.74%)
Pentagonal	2 (13.33%)	7 (7.78%)	6 (6.32%)
Hexagonal	-	14 (11.11%)	8 (8.42%)
Round	3 (20.00%)	7 (7.78%)	15 (15.79%)
Tetragonal	-	2 (2.22%)	3 (3.16%)
Irregular	1 (6.67%)	6 (6.67%)	9 (9.47%)

CT: Computed tomography; FM: Foramen magnum

Table 4. Age related changes of foramen magnum

Measurements and Age groups (18-67 years)		Mean±SD	Min.-Max.	P value
FML	Group-1 (18-20 years) (n=22)	3.64±0.48	2.85-4.51	0.031
	Group-2 (21-30 years) (n=29)	3.84±0.46	3.19-4.90	
	Group-3 (31-40 years) (n=34)	3.70±0.53	2.63-4.71	
	Group-4 (41-50 years (n=40)	3.66±0.48	2.35-5.01	
	Group-5 (51-60 years) (n=47)	3.74±0.43	3.01-4.91	
	Group-6 (61-67 years) (n=13)	3.31±0.26	2.97-3.76	
FMW	Group-1 (18-20 years) (n=22)	3.30±0.57	2.04-4.13	0.040
	Group-2 (21-30 years) (n=29)	3.50±0.47	2.86-4.89	
	Group-3 (31-40 years) (n=34)	3.37±0.41	2.55-4.14	
	Group-4 (41-50 years (n=40)	3.16±0.49	1.98-4.31	
	Group-5 (51-60 years) (n=47)	3.27±0.42	2.44-4.58	
	Group-6 (61-67 years) (n=13)	3.13±0.41	2.04-3.43	
FMI	Group-1 (18-20 years) (n=22)	90.68±10.69	67.13-106.67	0.138
	Group-2 (21-30 years) (n=29)	91.34±8.42	71.97-108.67	
	Group-3 (31-40 years) (n=34)	92.59±14.97	63.91-122.05	
	Group-4 (41-50 years (n=40)	86.68±11.28	65.18-104.86	
	Group-5 (51-60 years) (n=47)	88.01±11.87	63.71-118.27	
	Group-6 (61-67 years) (n=13)	94.64±12.96	68.69-114.33	

SD:Standard deviation; Min.: Minimum; Max.; Maximum

DISCUSSION

FM is the biggest hole and is located at back of the basilar part of occipital bone and posterior cranial fossa. It consists of four parts as basilar part (1), squamous (1) part and lateral parts (2) and surrounds the FM[1,2,5,18]. The FM is an crucial structure in skull that taken into account in most medical fields, including forensic and physical anthropology, comparative anatomy, biology, surgery of the foramen structures and for the craniovertebral junction. There are many structures around of the FM such as basion (the front-middle part of FM), opisthion (back-middle of FM), canalis condylaris, hypoglossal canal[1,2,18]. The basion and opisthion reference points are important craniometric points. There are morphological differences between gender. Generally, the sagittal (length) and transvers (width) diameters are greater in males than in females[5,10]. The FM is a passage of the central nervous system through the skull and connects the brain with the spinal cord. The position of the foramen magnum is essential for posture in orthostatism as it allows a correct relationship between the skull and the cervical spine. This hole includes the medulla oblongata, meninges, vertebral arteries, spinal root of cranial nerve XI, anterior and posterior spinal arteries, the tectorial membrane, and alar ligaments[5,11,14].

Additionally, the FM morphometry and morphology play an important role in accurate diagnosis, treatment and neurologic interpretation[2,4]. Several anatomic proportions such as the shape and size of the FM should be taken into consideration during surgery concerning the posterior and lateral craniovertebral junction[4]. The FM size analysis is clinically relevant in patients with achondroplasia and in forensic medicine abot sex determination[10]. Various studies declared the FM shapes'discrepancies which are classified as two semicircles, oval, egg-shaped, round, tetragonal, pentagonal, hexagonal, and irregular play an important role in the diagnostic, clinical, and radiologic investigations. In FM herniation, meningioma and achondroplasia, the crucial structures may be compressed and FM stenosis may cause respiratory depression and increased sudden infant death rate[11,14]. In a study performed with 60 adult dry skulls by Ulcay et al., the mean values of the CW, CL, CW/FMW, CL/FML, FMW (observed), FMW (prediction), FML (observed) and FML (prediction) were found to be 129.45±4.99mm, 162.45±6.20mm, 4.62±0.35, 4.62±0.50, 28.14±1.77mm, 28.01±1.07mm, 35.81±7.56mm and 35.16±1.34mm, respectively. Also, the CW/FMW and CL/FML values were found as 4.62 in both measurements. So, it was suggested that FMW and FML might be presumed by using CW and CL by accepting the coefficients means (4.62) as Golden Ratio (GR) in a study performed by Ulcay et al. In the same study, the width and the length index were found approximately equal each other as 1.01. Additionally, the frequency of different shapes of FM were investigated and the most frequent type of the FM shape was determined as oval (20%) and the least seen type was reported as round (6.67%)[2].

In an other study evaluating the craniometric data of the ninty-one Thai cadaveric dry skulls, the CW, CL, FMW and FML mean values were reported as 144.13±5.45mm, 173.09± 4.74mm, 30.71±2.05mm and 36.78±2.14mm in males, respectively. The same values were 140.83±5.40mm, 165.15±6.61mm, 28.90±1.89mm and 34.29±2.35mm in females, respectively. On the other hand, the GR values (obtained from the means of the CW and FMW and the means of the CL and FML) of FML and FMW for males were approximately 4.69 and 4.71, respectively. The same values for females were found to be 4.87 and 4.816, respectively. According to result, the width and length index were found to close each other (0.996 for males, 1.165)[19]. Sangvichien et al. performed with 101 Thai skulls (66 males and 35 females) aged between 18 and 86. In this study, the CW, CL, FMW, FML mean values were reported to be 143.58±6.02 mm, 169.16 ±8.08 mm, 30.68± 2.26 mm, 35.39±2.99mm for males, respectively[20]. The corresponding values of females were 140.56± 6.00mm, 165.82±5.74mm, 30.10±2.64mm and 34.76±2.08mm, respectively. The GR values (obtained from the means of the CW and FMW and the means of the CL and FML) were evaluated as 4.68 and 4.78 for males, 4.67 and 4.77 for females, respectively[16]. The CW (149.33mm), CL (181.22 mm), FMW (32.98 mm), FML (37.06 mm) of males and the GR of FMW (4.53) and FML (4.89) were calculated. The same values were 144.22mm, 172.59 mm, 30.95mm and 35.47 mm, respectively. The GR of FMW (4.66) and FML (4.87) were determined in females, respectively in Burdan et al's study performed by using 3D CT images in 313 individuals (142 males, 171 females) aged 20–30 years. In the same study, the most frequent and the least seen FM shape were wide oval (36.62%) and two semicircle (17.61%) in males and wide oval (39.18%) and two semicircle (19.30%) in females[16]. In present study, the CW/FMW ratio was 4.26 for dried skulls, 4.66 for females and males. Also, the CL/FML ratio were 4.51 for dried skulls, 4.16 for females and 4.33 for males. The width/length index values were 0.87 in dried skulls, 0.90 for males and females CT, respectively. These values were found close to each other.

There were many studies about FM types. The oval shaped FM was most frequently seen in Singh et al.' study conducted on 62 Indian dry skulls of unknown gender obtained from the Department of Anatomy[13]. Additionally, in other study included in one hundred forty-four crania and 208 occipital bones, a total of 352 dry adult skulls, obtained from the Turkish population to measure the dimensions and determine the localization of the FM, the most frequent FM type was reported as tetragonal and semicircle type when the least encountered type was round type[4]. In present study, the most common shape was oval (26.67%) in dried skulls, followed by egg (20%) and round (20%), two semicircle (13.33%), pentagonal (13.33%) and irregular type (6.67%). In females, the most frequently type was oval (23.33%) and the most rare type was tetragonal type (2.22%). While in males, the most frequently type was oval (28.42%) the least seen type was tetragonal type FM (3.16%).

In briefly, anatomical knowledge of the FM is significant for understanding the pathophysiology of various disorders of the craniovertebral junction. FM has many clinical importance for both pathologic problems and planning surgical procedures (about how much bone must be removed). In early fetal development, FM is one of the centres of ossification. Also, its shapes are variable because of evolutionary changes. The irregular shape of the FM might be a reason for developmental anomalies related to bones and soft tissues at the craniovertebral junction[9,13]. The morphometric study of FM is crucial for anatomists, neurosurgeons, orthopedicians, radiologist and anesthetist. FM type variations become crucial from diagnostic, clinical and radiological aspects and these types forms approximately from 8 types; oval, semicircle, egg, round, tetragonal, hexagonal, pentagonal and irregular[2,4,9,13,17]. The variations in the types of the FM may be affected some factors; various ethnical group, sample size, sexual dimorphism and types of population[9]. The morphological differences of FM are noticed in different population and this depends on genetic, environment and socio-economic factors. These variations have become significant due to newer imaging techniques like CT, and MRI in the subject of diagnostic medicine[13].

Dried skulls'numbers were limited. Because, partially fragmented and broken and unclear bones having unclear reference landmark were excluded from the study. Also, there is not enough study analyzed relation with skulls and FM harmony. So, the comparison of the other studies'results is limited. Further research is needed to prove this idea clearly.

The present study provided a useful and reliable method based on CT and photograph measurements with DSLR camera to analyze the cranium and FM morphometry. The presence of harmony was investigated also. It is understood from the literature data that FM is an important parameter in understanding underlying some disorders of the craniovertebral junction pathophysiology. Anatomical knowledge of FM morphometry and morphology may help many disiplines such as anatomy, neurosurgery, radiology and anaesthesia. Moreover, FM morphometry seems to be affected by several factors including various ethnical group or different population, sample size, sexual dimorphism and types of population, genetic, environment and socio-economic factors.

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