MEDICAL RECORDS-International Medical Journal

Research Article

Anatomical Analysis of Foramen Magnum: A 3D Slicer CT Study

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Abstract

Aim: To analyze the anatomical structure of foramen magnum in healthy individuals according to age/gender.

Material and Methods: Cranial Computed Tomography (CT) images of 130 healthy individuals (60 female, 70 male) the 18-84 age were included in our study. Using the 3D Slicer software package on these images, the Anterior-Posterior Diameter (APD), Transverse Diameter (TD), perimeter, area, angle between the posterior edge of the foramen magnum and the clivus (FMC) value, and index were found. The shapes of the foramen magnum were analysed.

Results: There was no statistical significance between age, FMC, and foramen magnum index values in both genders ($p>0.05$). APD, TD, perimeter, and area values of males were statistically higher ($p<0.05$). The average foramen magnum index was 85.61±6.5 in the whole group, 84.94±7.04 in males, and 86.29±5.67 in females. There was no statistical relationship between age and measurement parameters in the whole group ($p>0.05$). Seven shapes of foramen magnum have been seen. The most common was the oval shape (27.7%) and the least common was the pentagon (1.5%).

Conclusion: Knowing the anatomical structure of the foramen magnum is important in terms of identity and ethnicity. We also think that our results may contribute to the surgical treatment of the foramen magnum and adjacent structures.

Keywords: Computed tomography, gender, foramen magnum, morphology, morphometry.

INTRODUCTION

Foramen magnum is a part of the occipital bone and is the largest opening in the lower part of the skull. Anatomically, it is located in the posterior cranial fossa and is surrounded by parts of the occipital bone (1). Although it is defined as oval-shaped, there is information in the literature that it has different shapes and sizes. It can be in different shapes such as ellipse, egg, round, hexagonal, pentagonal, tetragonal, and irregular (2-4). Foramen magnum is adjacent to structures at both ectocranial and endocranial borders (5). These structures are the spinal cord, meninges, accessory spinal nerve, dural sinuses, tectorial membrane, alar ligament, vertebral, and spinal arteries (1,6). For this reason, the foramen magnum is important for clinicians regarding hemodynamic, hydrodynamic, and locomotor function (5). In addition, the morphological and morphometric structure of human bones is used in identification in forensic medicine and archaeological studies (7). It is reported that there is an accuracy rate of around 90% in identification studies conducted on skull bones (8).

Foramen magnum may follow a course associated with brain development. It has been reported that diseases such as Chiari malformation and Syringomyelia show changes in bone structure (9,10).

Previous studies reported measurements from skull bones (2,6). In recent years, Computerised Tomography (CT) has been used for identification, especially in forensic cases (11).

Morphometric analysis of the area, circumference, anteroposterior diameter (APD), and transverse diameter (TD) of the foramen magnum was examined with different methods. In recent years, with the development of the field of computer science and bioinformatics, there are many new software tools. One of these software is 3D Slicer. 3D Slicer is free and open access and can make automatic calculations using medical image data of patients (12).

Our aim in this study is to examine the anatomical structure of the foramen magnum according to age/gender using the 3D Slicer software tool.

CITATION

Gurlek Celik N, Akman B. Anatomical Analysis of Foramen Magnum: A 3D Slicer CT Study. Med Records. 2023;5(Suppl 1):182-6. DOI:1037990/medr.1359406

Received: 13.09.2023 **Accepted:** 09.10.2023 **Published:** 19.10.2023

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MATERIAL AND METHOD

Cranial CT images of 130 healthy individuals (60 female, 70 male) of the 18-84 age were included in our study between January 2023 and May 2023. Individuals who had not undergone cranial surgery had no traumatic pathology at the craniocervical junction, or had no congenital or traumatic craniofacial deformity were included in the study.

The approval of the Amasya University Non-Interventional Clinical Research Ethics Committee (Date: 13.06.2023, Approval Decision No: 2023/103) was obtained.

GE Healthcare Revolution EVO CT (multi-detector CT, 128 slices) device was used in the images. Cranial CT images with a section thickness of 0.625 mm were used. In our study, CT data were recorded in the DICOM format using the PACS system. Images were analysed with 3D Slicer version 5.2.1 (https://www.slicer.org/) (12).

In this study, the APD, TD, perimeter, area, and angle between the posterior edge of the foramen magnum and clivus (FMC) value were examined with the "Markups" tool in the 3D Slicer program. In addition, the index value was formulated and its anatomical shapes were examined (Figures 1,2 and 3). It was calculated as foramen magnum index (TD/APD)*100.

Classification of foramen magnum index values was made. Small: a–81.9, medium: 82.0–85.9, large: 86.0–a (13).

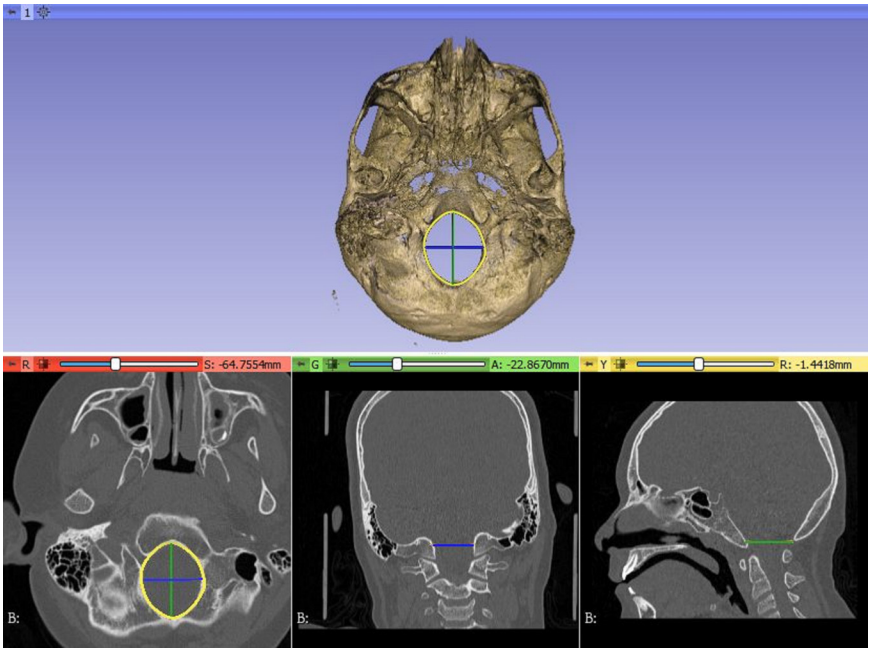

Figure 1. Axial, coronal and sagittal view of foramen magnum measurement with 3D Slicer (Green line----APD, blue line-----TD, yellow line----- Perimeter)

Figure 2. Angle between the posterior edge of the foramen magnum and the clivus (FMC)

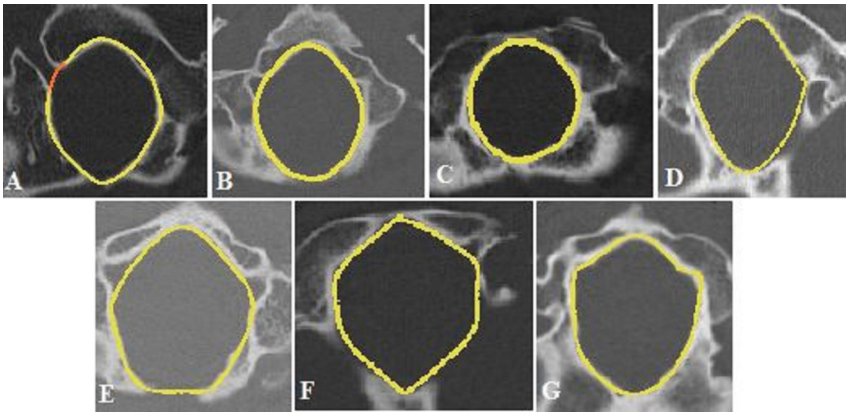

Figure 2. Angle between the posterior edge of the foramen magnum and the clivus (FMC)

Statistical Analysis

Data were analyzed in IBM SPSS V26 software. Descriptive statistics; It is expressed as several units (n), percentage (%), mean ± standard deviation, median and interquartile distance values. Data were evaluated with the Shapiro-Wilk normality test. The homogeneity of variance of the groups was analysed with the Levene test. Numerical variables by gender were performed by independent samples t-test or Mann-Whitney U test. The relationships between age and other numerical variables were evaluated with the Spearman correlation coefficient (14). The significance value was considered as statistical p<0.05.

There was no statistical difference between age, FMC and foramen magnum index values in both genders (p>0.05).

Table 1. Comparisons by gender

Variables	Sex		Test statistics	
	Male n=70	Female n=60	Test value	p value
Age	28.0 (27.0)	24.0 (31.5)	0.781	0.435‡
TD (mm)	31.77±2.30	29.84±2.08	4.977	<0.001†
APD (mm)	37.54±2.83	34.65±2.25	6.490	<0.001†
Perimeter (mm)	109.29±7.50	100.57±7.30	6.697	<0.001†
Area (cm²)	8.90±1.17	7.43±0.93	7.851	<0.001†
FMC	123.13±6.20	123.45±7.35	0.266	0.790†
Foramen Magnum Index	84.94±7.04	86.29±5.67	1.189	0.237†

Data are given as mean±standard deviation or median (interquartile) distance. †: Independent samples t test. ‡: Mann-Whitney U test.

Table 2: Correlations between age and other variables

Variables	Whole Group		Male		Female	
	rho	p	rho	p	rho	p
TD (mm)	-0.009	0.918	-0.057	0.637	-0.054	0.680
APD (mm)	-0.114	0.195	**-0.338**	**0.004**	-0.058	0.662
Perimeter (mm)	-0.082	0.352	**-0.274**	**0.022**	-0.042	0.750
Area (cm²)	-0.088	0.319	**-0.239**	**0.046**	-0.123	0.348
FMC	0.167	0.057	0.147	0.223	0.182	0.164
Foramen Magnum Index	0.164	0.062	**0.257**	**0.032**	0.055	0.676

TD: transvers diameter, APD: anterior posterior diameter, FMC: angle between the posterior edge of the foramen magnum and the clivus, rho: Spearman correlation coefficient

RESULTS

There was no statistical difference between age, FMC, and foramen magnum index values in both genders (p>0.05) (Table 1). The average foramen magnum index was found to be 85.61±6.5 (medium) in the whole group, 84.94±7.04 (medium) in males, and 86.29±5.67 (large) in females. The APD, TD, perimeter, and area values of males were higher (p<0.05). No significant relationship was found when age and other variables were compared throughout the group. Weak negative correlation between age and APD, perimeter and area values of males; there is a weak positive correlation with the foramen magnum index values. No relationship was found between age and measurement parameters in females (p>0.05) (Table 2).

DISCUSSION

Skull bones are important for forensic science and anthropologists in gender determination or ethnicity research. Because it has been reported that the skull bones show an accuracy of 90% in sex determination (15-17). Many studies have been conducted on the foramen magnum. Our aim in this study is to examine the anatomical structure and index value of the foramen magnum according to age/gender using the 3D Slicer software tool. The morphology and morphometry of skull bones have been examined in many studies (2,6). In addition, there are studies on CT images (18,19).

Chethan et al. (2) examined the morphometry of the foramen magnum in 53 dry bones. The average APD value was reported as 31±2.4 mm and the TD value as 25.2±2.4 mm. Another study analysed the foramen magnum on 77 dry bones of the Brazilian population aged 18 and over. The study reported the average APD value as 34.23 mm and TD as 28.62 mm. Additionally, the average index value was reported as 83.75 mm (20). The results differed from our study. We think that the reason for these differences may be due to sample size, measurement technique and the fact that the studies were conducted on dry bones.

Govsa et al. (6) study of 352 dry bones, the mean APD value was 37.2 mm, the TD value was 30.8 mm, and the foramen magnum index was 84.02 mm. Although our study was not conducted on dry bones, it is similar to the results obtained (APD: 36.2 mm; TD: 30.8 mm; foramen magnum index: 85.5). Vinutha et al. (18) study, the foramen magnum index value was reported as medium in both genders. Our study determined it as a medium in males and large in females. Differences in results may be related to ethnicity.

Meral et al. (21) reported in their study the APD, TD, area, and index values from the CT images of 600 people (300 males, 300 females) aged between 21 and 50. They examined the study according to age groups and genders, five years in each group. It has been reported that there is no difference between age groups and foramen magnum measurements. In addition, males were found to be higher than females in all measurements, and this difference was reported to be statistically significant. Aljarrah et al. (4) They examined 472 CT images (236 males, 236 females) in the Saudi Arabian population aged 18-72. It has been reported that there are significant differences when compared by gender. In their CT study, Tellioğlu et al. (22) analysed APD, TD, and perimeter and area measurements of 100 individuals (50 males, 50 females). Significant differences between genders were reported in all variables. It was also stated that males had a higher average. Meral et al. (21), Aljarrah et al. (4) and Tellioglu et al. (22) results are compatible with our study.

Botelho et al. (23) reported the FMC value of the control group as 126±9.4°, and Ferreira et al. (24) reported the same angle in the control group as 126.20±9.6° in their study. The findings are consistent with our results. Sun et al. (19) study, the average FMC value was reported as 153.46±9.1° in females and 149.93±8.6° in males. A significant difference was reported in both genders ($p<0.001$). It was reported to be significant according to the age variable. In our study, the FMC value was high in females. However, no difference was found between age and gender. The findings were higher than our results. Differences in results may be the sample size and the structural differences. We believe that the differences in the results may be important in terms of surgery.

It is known in the literature that the foramen magnum varies morphologically. This may cause differences in structures at the craniovertebral junction (25). In our study, oval-shaped foramen magnum was the most common type with 27.7%. Pires et al. (20) found oval-shaped foramen magnum in a dry bone study with a rate of 53.24%. Our results were lower than in this study (Table 3). Taib et al. (26) reported an oval-shaped foramen magnum at a rate of 14%, but this rate was lower than our results. Differences in results may be related to ethnic origin. Kum et al. (3) analysed 314 CT images in their study. They found the most common oval-shaped (39.09%) and the most rare egg-shaped (1.59%) foramen magnum.

Table 3. Frequency of different morphological shapes of foramen magnum

Types of shapes	Female		Male		Whole group	
	n	%	n	%	n	%
Oval	20	33.3	16	22.9	36	27.7
Egg	4	6.7	4	5.7	8	6.2
Round	2	3.3	11	15.7	13	10.0
Tetragonal	10	16.7	13	18.6	23	17.7
Pentagonal	1	1.7	1	1.4	2	1.5
Hexagonal	16	26.7	14	20.0	30	23.1
Ireegular	7	11.7	11	15.7	18	13.8
Total	60	100.0	70	100.0	130	100.0

In another CT study, the frequency of appearance of foramen magnum shapes was reported as follows: hexagonal (30.72%), irregular A (20.34%), oval (15.25%), irregular B (13.14%), round (7.42%), egg (5.72%), pentagonal (4.24%) and tetragonal (3.18%) (4). Chethan et al. (2) reported that round shape was the first and pentagonal shape was the last in terms of frequency. The results differ from our current study. Differences in results may be related to sample size.

Limitations of our study; this may be due to the fact that it is single-centered, retrospective and the number of samples is limited.

Foramen magnum is very important due to its location. While it may vary from person to person, differences in ethnicity may also affect bone structures. Therefore, we think that the anatomy of the foramen magnum will be important for clinicians and anthropologists.

CONCLUSION

In our study, the anatomical structure of the foramen magnum of a healthy individual was examined according

to age/gender variable, and the differences were recorded. Foramen magnum index was in the medium category in the entire group, medium in males, and large in females. Males' APD, TD, perimeter, and area values were statistically higher. It was determined that males showed a weak negative correlation between age and APD, perimeter, and area values in all parameters except the foramen magnum index. When age and other parameters were compared in females, the results were not significant.

We believe that measurements and analysis of the foramen magnum will contribute to clinical diagnosis and treatment.

Financial disclosures: *The authors declared that this study has received no financial support.*

Conflict of Interest: *The authors declare that they have no competing interest.*

Ethical approval: *Amasya University Non-Interventional Clinical Research Ethics Committee (Date: 13.06.2023, Approval Decision No: 2023/103) was obtained.*

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