

## Morphometric Evaluation of the Foramen Magnum and Variations in its Shape: A Study on Computerized Tomographic Images of Normal Adults

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**Abstract:** The purpose of this study was to evaluate the radiological measurements of the foramen magnum (FM) and their relation to sex as well as to note variations in the shape of the FM. Cranial computerized tomographic images (CT) of 110 normal subjects (57 males - 53 females) between the ages of 18 and 80 years were examined in this study. The sagittal and transverse diameters of the FM were measured with a millimetric sliding caliper. Additionally, the area of the FM was also estimated. The statistical analysis for sex comparison was made using Student's t test. To determine the relationships between the studied parameters, Pearson correlation coefficients were calculated. In addition, the frequency percentage ratios of the variable shape types of the FM were also determined. Our findings showed that the sagittal, transverse diameters and area of the FM were significantly greater in males than in females ( $P < 0.001$ ). The statistical comparisons of the correlations between all measuring parameters showed significant associations ( $P < 0.01$ ). According to the identity with the shape type, the FM was found to be oval in 8.1%, egg-shaped in 6.3%, round in 21.8%, tetragonal in 12.7%, pentagonal in 13.6%, hexagonal in 17.2%, irregular (A) in 10.9% and irregular (B) in 9.09%. It can be concluded that the sex differences in the dimensions of the FM and the variations in its shape are of diagnostic clinical and radiological importance.

**Key Words:** Foramen magnum, Measurements, Variations

### Introduction

The base of the cranium is so complex that it is very interesting to study the diameters of the foramen magnum (FM), from a descriptive and topographic points of view, due to the important relation of the FM with its contents. Additionally, the dimensions of the FM have clinical importance because the vital structures that pass through it may suffer compression such as in cases of FM achondroplasia (1) and FM brain herniation (2,3). In a transcondylar surgical approach to the FM, such as in the resection of tumors of the FM region, the anatomic features of the FM and variations in the condylar resections to improve the exposure of this region have been considered in several studies (4-6). Wanebo et al. (7) stated that longer FM antero-posterior dimensions permitted greater contralateral surgical exposure for condylar resection. The anatomic and radiologic values of the FM have been the objectives of several studies.

Although the anatomic values obtained by different authors are nearly the same, this does not happen with radiologic values (8). The values radiographically obtained by Munoz (9) were about 0.5 mm higher than the anatomic values. The radiologic mean values obtained by Schmeltzer et al. (10) and Wackenheim (11) were 35 mm for the sagittal diameter and 30 mm for the transverse diameter, whereas Zaragoza (12) obtained mean values of 38 mm for the sagittal diameter and 28 mm for the transverse diameter. Classically, the anatomic diameters have been found to be about 35 mm for the sagittal diameter and 30 mm for the transverse diameter (13,14). Few reports on the area of the FM and its variations in shape are available. Catalina-Herrera (8) found that the mean area of FM in male and female skulls was 888.4 mm<sup>2</sup> and 801 mm<sup>2</sup>, respectively. Zaidi and Dayal (15) reported that the FM was oval in 64% in their studied skulls. However, Sindel et al. (16) could only find

an oval foramen in 18.94% of skulls, and in 81.06% of skulls the shapes of the foramen were other than oval.

Considering the above-mentioned values, the aim of the present study was to evaluate the radiologic metric values of the FM and their relation to sex as well as to note variations in its shape.

**Materials and Methods**

By use of a PQS 2000 (Picker, USA) spiral CT scanner, computerized tomographic images (CT) of the FM of 110 normal subjects (57 males - 53 females) between the ages of 18 and 80 years were obtained from the Radiology Department, Faculty of Medicine, Selçuk University. Scanning at the orbitomeatal line is usually used for routine cranial CT images (17). From continuous 3 or 5 mm-thick slices and parallel to the orbitomeatal line, the best image of the FM was selected. Others were scanned at 0° horizontally from the top of the hard palate through the FM to the occiput (18). The maximum sagittal (basion – opisthion distance) (SD) and transverse (TD) diameters of the FM were measured with a millimetric sliding caliper. The magnification factor was determined for each scan and the final lengths expressed in millimeters. In the present study, the area of the FM was also estimated; this was automatically given in the CT images. By visual examination of the images of the studied subjects, variations in the shape of the FM were determined and reported in this study. The statistical analysis for sex comparison was made by Student’s t test. To determine the relationships between the studied parameters, Pearson correlation coefficients were calculated.

**Results**

Comparative statistics with the maximum and minimum values, means and standard deviations for each dimension of the FM in both males and females are presented in Table 1. In males, it was found that the maximum values were 45 and 40 mm, whereas the minimum values were 31 and 27 mm for the sagittal and transverse diameters, respectively (Table 1). The maximum values obtained for female subjects were 42 and 33 mm, whereas the minimum values were 28 and 24 mm for the sagittal and transverse diameters, respectively (Table 1). The SD, TD and FM area in males were significantly greater than in females (P < 0.001) (Table 1). Statistical comparisons of the correlations of all measured parameters are shown in Table 2. The area of the FM showed highly significant correlations for both SD (r = 0.847) (P < 0.01) and TD (r = 0.834) (P < 0.01). The maximum and minimum areas found in males and females were 1266 and 710 mm<sup>2</sup> and 1006 and 677 mm<sup>2</sup>, respectively; the means ± SD were 931.7 ± 144.29 mm<sup>2</sup> and 795 ± 99.32 mm<sup>2</sup>, respectively (Table 1). In males, the means ± SD were 37.2 ± 3.43 and 31.6 ± 2.99 mm for the sagittal and transverse diameters, respectively (Table 1). In females, the means ± SD were 34.6 ± 3.16 and 29.3 ± 2.19 mm for the sagittal and transverse diameters, respectively (Table 1). The types of variable shapes of the FM with an identically reported number of cases and their percentages are shown in Table 3. The FM was oval in 9 subjects (8.1%) (Fig. 1); egg-shaped in 7 subjects (6.3%) (Fig. 2); round in 24 subjects (21.8%) (Fig. 3); tetragonal in 14 subjects (12.7%) (Fig. 4); pentagonal in 15 subjects (13.6%) (Fig. 5); hexagonal

Table 1. Maximum, minimum, means, standard deviations, t and P values for foramen magnum parameters-gender comparative results.

Parameters	Males (n = 57) Values			Females (n = 53) Values			t	P
	Max. (mm)	Min. (mm)	Mean ± SD (mm)	Max. (mm)	Min. (mm)	Mean ± SD (mm)		
SD	45	31	37.2 ± 3.43	42	28	34.6 ± 3.16	4.13	0.000
TD	40	27	31.6 ± 2.99	33	24	29.3 ± 2.19	4.49	0.000
AREA	1266 (mm <sup>2</sup> )	710 (mm <sup>2</sup> )	931.7 ± 144.29 (mm <sup>2</sup> )	1006 (mm <sup>2</sup> )	677 (mm <sup>2</sup> )	795.0 ± 99.32 (mm <sup>2</sup> )	5.51	0.000

P < 0.001

Table 2. Correlation coefficients (r) between the foramen magnum measurements.

	SD	TD
AREA	0.847	0.834
TD	0.624	

All correlations were significant at the  $P < 0.01$  level

Table 3. Types of foramen magnum shape - number of cases and percentages.

TYPE	No. of cases	%
Oval type	9	8.1
Egg type	7	6.3
Round type	24	21.8
Tetragonal type	14	12.7
Pentagonal type	15	13.6
Hexagonal type	19	17.2
Irregular type (A)	12	10.9
Irregular type (B)	10	9.09

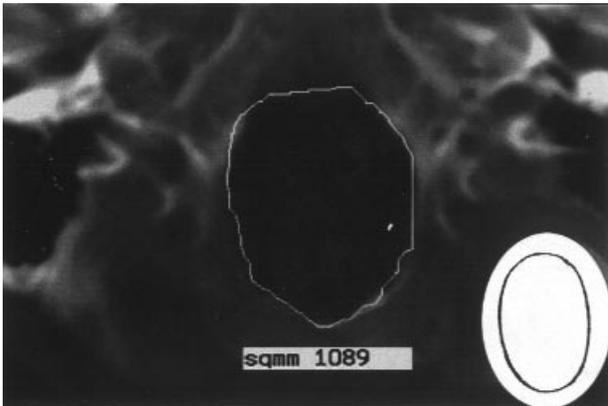


Figure 1. Oval FM (CT image with schematic diagram).

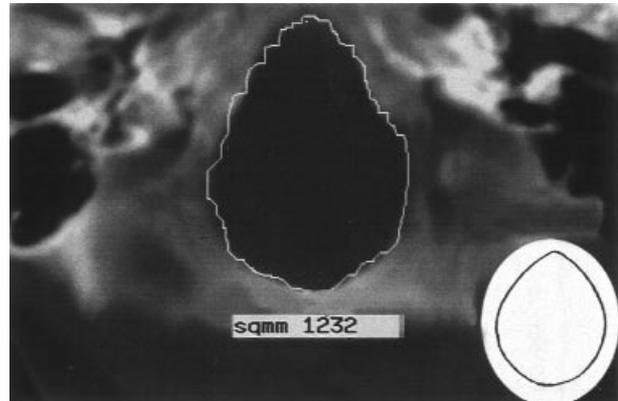


Figure 2. Egg-Shaped FM (CT image with schematic diagram).

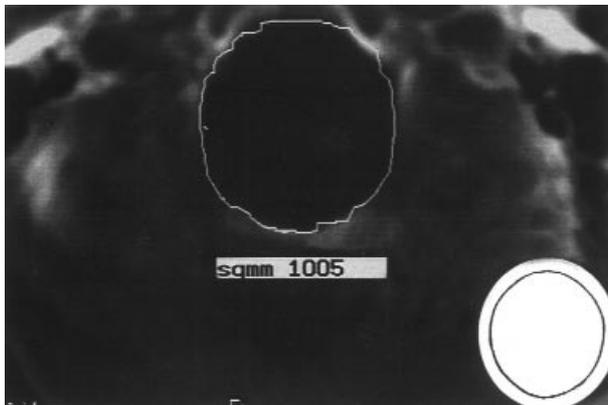


Figure 3. Round FM (CT image with schematic diagram).

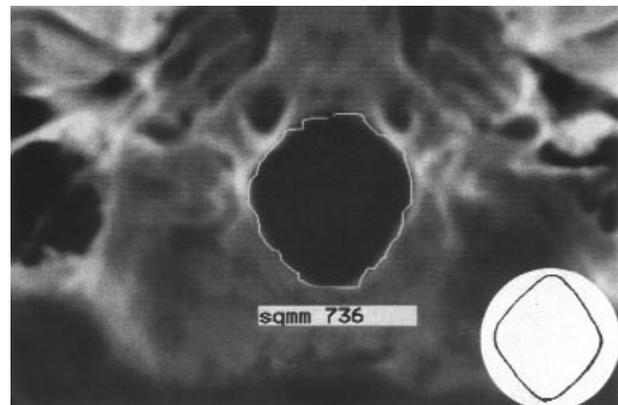


Figure 4. Tetragonal FM (CT image with schematic diagram).

in 19 subjects (17.2%) (Fig. 6); irregular (A) in 12 subjects (10.9%) (Fig. 7), and irregular (B) in 10 subjects (9.09%) (Fig. 8).

### Discussion

In this study, the results were 45 and 40 mm as the maximum sagittal and transverse diameter, respectively,

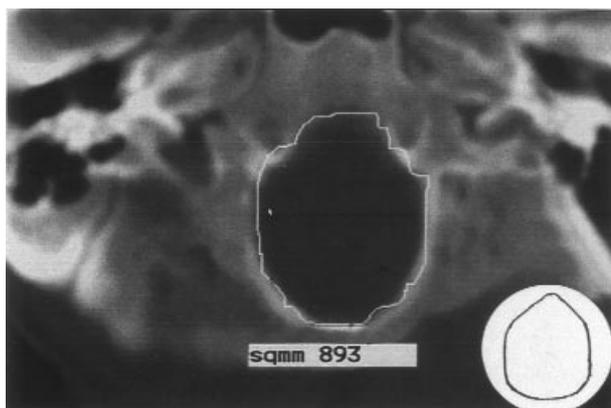


Figure 5. Pentagonal FM (CT image with schematic diagram).

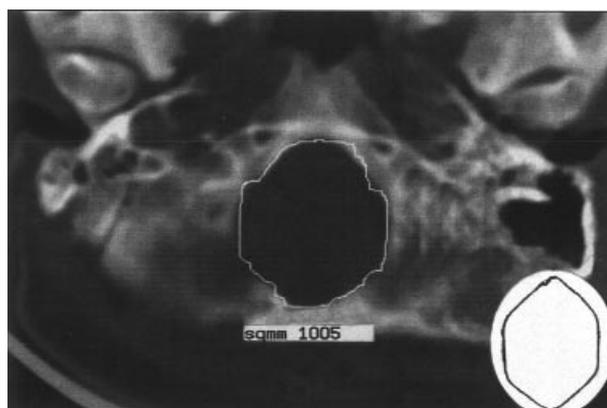


Figure 6. Hexagonal FM (CT image with schematic diagram).

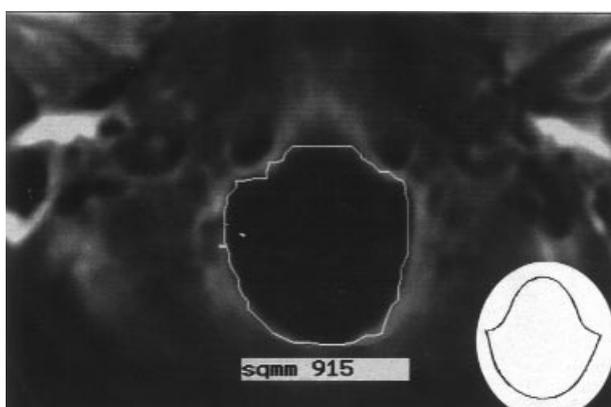


Figure 7. Irregular (A) (CT image with schematic diagram).

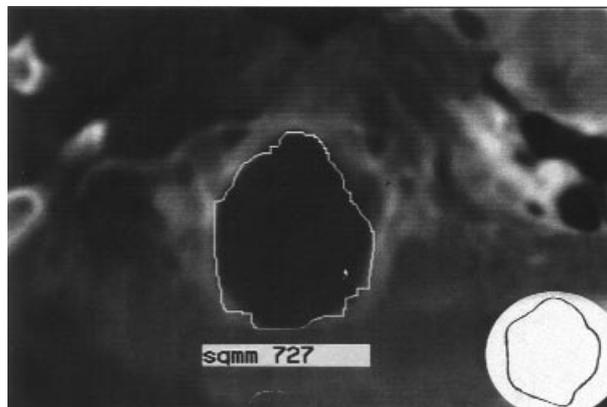


Figure 8. Irregular (B) (CT image with schematic diagram).

in male subjects, and 42 and 33 mm respectively for female subjects. The minimum values were 31 and 27 mm for the sagittal and transverse diameters in male subjects, and 28 and 24 mm for the same parameters in female subjects. The mean in males was  $37.2 \pm 3.43$  mm for the sagittal diameter and  $31.6 \pm 2.99$  mm for the transverse. In females, the mean was  $34.6 \pm 3.16$  mm and  $29.3 \pm 2.19$  mm, respectively. If male and female subjects are considered together, the mean for the sagittal diameter is  $35.9 \pm 3.29$  mm and the mean for the transverse diameter is  $30.4 \pm 2.59$  mm. Thus, our results are in agreement with the results obtained by Schmeltzer et al. (10) and Wackenheim (11). Şendemir et al. (19), studying the FM measurements of 23 subjects through CT images obtained for the SD and TD a mean of 36.4 mm and 30.0 mm, respectively. These results are very close to our findings, being 0.5 mm greater than ours in the SD and 0.4 mm lower than ours in the TD.

Other authors, such as Fischgold and Wackenheim (20), reported that the minimum radiographic value for the sagittal diameter is 27 mm, whereas in ours it is 28 mm.

Wackenheim (11) obtained radiographically mean values of 35 mm and 30 mm for the sagittal and transverse diameters, respectively. Compared with our results, without sex distinction, we can see that these values are slightly lower than ours.

In Catalina-Herrera's anatomic study of the FM (8), the diameters were 35.2 mm for the sagittal and 30.3 mm for the transverse diameter. Similar values were obtained by Testut and Latarjet (14). These results are similar to our findings.

Other authors said that the normal values for the SD measurements of the FM lie between 28.5 mm (19) and 48.0 mm (21), and for the TD measurements 21.4 mm (22) and 40.0 mm (21). The differences between the

radiographic and the anatomic values and even among the radiographic values are possibly due to the radiologic techniques used by the different authors.

In the present study, the high significant correlations between the evaluated parameters obtained indicate that proportional growth rates occur in the dimensions of the normal FM.

The FM is usually described as oval in shape (23-29). In a study of 200 skulls, Zaidi and Dayal (15) reported that oval FMs were found in 128 (64%) skulls. Sindel et al. (16) and Lang et al. (22) reported that this shape was not found in more than 22.35% and 18.94%, respectively, of their samples. In our study, oval FMs were only observed in 9 (8.1%) subjects. The FM was hexagonal in 24.5%, pentagonal in 7.5%, irregular in 3.5% and round in 0.5% of the skulls studied by Zaidi and Dayal (15), whereas in the skulls studied by Sindel et al. (16), the FM was hexagonal in 5.26%, pentagonal in 4.21%, irregular in 6.31%, round in 15.78% and tetragonal in 49.42%. In their observations, Lang et al. (22) stated that round FMs were identified in 7.05% of subjects.

In our study, the FM was found to be egg-shaped in 7 (6.3%) skulls, round in 24 (21.8%) skulls, tetragonal in 14 (12.7%) skulls, pentagonal in 15 (13.6%) skulls, hexagonal in 19 (17.2%) skulls, irregular (A) in 12 (10.9%) skulls and irregular (B) in 10 (9.09%) skulls. However, regarding this topic, the controversial results reported by the different authors could be made the focus of further intense studies in the future after taking into consideration the relationships between these variations in the shape of the FM and the effects of the vital structures passing through it.

Catalina-Herrera (8) stated that the means of the FM area found in male and female skulls were 888.4 mm<sup>2</sup> and 801 mm<sup>2</sup>. Our results showed that in male and

female subjects they were 931.7 ± 144.29 mm<sup>2</sup> and 795 ± 99.32 mm<sup>2</sup>, respectively. By comparing our results with those mentioned above, a difference of 43.3 mm<sup>2</sup> in males was smaller than that obtained by our study, and in females a difference of 6.0 mm<sup>2</sup> was greater. Wanebo et al. (7), in their study on cadaveric CT images measurements, found that the mean area of the FM is 820.0 ± 100.0 mm<sup>2</sup>, the mean length (SD) 36.0 ± 2.0 mm and the mean width (TD) 32.0 ± 2.0 mm. If we combined our male and female mean values together, these results show a difference of 43.35 mm<sup>2</sup> in FM area, 0.1 mm in the SD and 1.6 mm in the TD. These unconsiderable differences are possibly due to the different measurement techniques followed in the 2 studies or are a result of the variety in the studied samples.

It can be concluded that our results are mostly in agreement with those of other authors. Significant sex differences in the quantified parameters indicate that the FM is larger in males. In adults, the shape of the FM is variable and remains controversial in the reports of different authors. However, it should be noted that sex differences in the dimensions of the FM and the variations in its shape should be taken into consideration during the performance of clinical and radiological diagnostics and during surgical approach.

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