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Morphometric analysis of the foramen magnum using cone beam computed tomography

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Background/aim: The aim of this study was to perform morphometric analysis of the foramen magnum (FM) using cone-beam computed tomography (CBCT).

Materials and methods: This study included CBCT images of 190 individuals (88 males and 102 females). The sagittal and transverse diameters and circumference of the FM were measured. The shape of FM was classified as round, hexagonal, oval, egg-shaped, tetragonal, pentagonal, irregular A, and irregular B. The data were statistically analyzed with chi-square and t-tests to assess the level of significance for sex and age.

Results: The means of its sagittal and transverse diameters and also circumference were higher in males than in females. Statistically significant differences were found between males and females for all variables ($P < 0.05$). No statistically significant difference ($P > 0.05$) was found between age groups for all variables. The round type was the most common, in 21.6% of the patients.

Conclusion: CBCT images can provide valuable information regarding FM and the measurements of its sagittal and transvers diameters and also its circumference may be reliably used for sexual dimorphism in anthropometric analysis and forensic medicine.

Key words: Cone-beam computed tomography, foramen magnum, forensic medicine, sex estimation

1. Introduction

Morphometric analyses of the cranium are routinely performed by clinical anatomists because identification of anatomical structures is essential before several surgical procedures (1). Moreover, anthropologists can categorize individuals and populations via physical morphology of the head and face as well as age, sex, and race discrimination (2). However, sex discrimination especially poses an important problem in unknown human skeletal remains for forensic medicine and forensic anthropology. To find a wholly intact skeleton in explosions, warfare, and other mass disasters almost always is impossible and complicated because of fragmented bones and broken body parts of victims, and so correct and careful applications are required (3,4). The skull, pelvis, and femora are the frequently useful bones and among these the pelvis is the best one for sex determination. When the complete skeleton exists, sex can be determined with 100% accuracy; this rate is 98% in the existence of both the pelvis and cranium and 95% with the adult human pelvis alone, and it declines to 80%–90% in the presence of the skull alone (4,5). The skull is the second best area for sex discrimination because craniofacial structures are relatively indestructible and less affected by environmental factors.

Several measurements of the skull such as the length, height, and circumference of the head, mastoid process, occipital condyle, and foramen magnum (FM) have been used for this analysis in previous studies (4–10). The FM is a three-dimensional aperture within the basal central region of the occipital bone (11) and also is a transition zone between the spine and skull. Its position between the brain and spinal cord plays an important role as an anatomic landmark (9). Therefore, the FM is a particularly interesting structure for anatomy, forensic medicine, and anthropology. Firstly, Teixeria in 1982 reported that the measurements regarding the FM can be helpful in estimation of sex (12) and since then various studies have been published about the evaluation of FM dimensions for sex estimation in different populations (3,4,9,13–18). Afterwards, it has been concluded that the measurements of its size and intracranial volume are reliable for determination of sexual dimorphism (3,13,18). On the other hand, Gruber et al. (9) did not detect any sexual dimorphism in the diameters of FM size in dry skulls from Central Europe. In addition, Günay and Altınkök (4) reported that the mean value of FM area in females is lower than in males, but it is never sufficient on its own for this matter.

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Forensic scientists and anthropologists reported that radiographic measurements may be more accurate and reliable than direct bone measurements for sex determination. The underlying reason is that these measurements provide clear images of skeletal features in cases where flesh is present (19,20). Two-dimensional imaging methods including antero-posterior and lateral cephalometric radiographs have been generally used in previous studies for skull measurements (18). The use of three-dimensional radiographic images like medical computed tomography (CT) has become more common in recent years (6,20–23). To the best of our knowledge, there is only one study regarding the evaluation of FM with cone-beam computed tomography (CBCT) (24). CBCT is a three-dimensional radiographic technique that can be used to assess cranial pathologies and anatomy (25). It has been concluded that CBCT images can provide valuable measurements for the maxillofacial structures (26).

The aim of this retrospective study was to investigate the morphometric analysis and variations in the shape of the FM using CBCT.

2. Materials and methods

This retrospective study was approved by the Ethical Board of the Institutional Ethics Committee of Gazi University, Ankara, Turkey (31.05.2016/E.67373). In our Radiology Clinic, informed consent was routinely obtained from all patients before CBCT examinations. The initial material of study consisted of the demographic data (sex and age) and CBCT images of 400 patients who presented to the Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Gazi University, between November 2014 and January 2015. The inclusion and exclusion criteria of the study were determined and modified in accordance with previous studies (6,20,22–24). The inclusion criteria were: 1) no trauma and surgery history of the head, 2) CBCT images are good quality and free of artifacts, 3) face-scanned CBCT images (field of view: 200 × 170 cm). The exclusion criteria were: 1) images with motion artifacts, 2) unclear images, 3) the patients aged under 17 years, 4) patients with a fracture or pathology in the region of the FM, 5) regional CBCT scans. Thus, CBCT images of 210 patients were excluded and 190 patients aged between 17 and 81 years were selected for the study.

The CBCT images were obtained using a Promax 3D unit (Planmeca, Helsinki, Finland), operating at 90 kVp, 9–14 mA, with a 0.16 mm voxel size, exposure time of 6 s, and a field of view of 8 cm. Scanning was performed by fixing the patient's jaw and the head support apparatus while the patient was standing. The images were examined by a dentomaxillofacial radiology resident (G.A.) with 2 years of experience with CBCT images. The images were analyzed with inbuilt software (Planmeca, Romexis viewer 2.7.0) on a 24-inch Nvidia Quadro FX 380 screen with 1280 × 1024 resolution in a quiet room with subdued ambient lighting. The observer was allowed to manipulate the contrast and brightness features and to use the zoom tool of the software for optimal visualization. The axial slices (thickness: 0.4 mm) of CBCT images were used. The observer was blinded to the sex and age of the patients. The size of the FM in sagittal and transverse directions and also its circumference were measured on CBCT scans (Figure 1). The same observer reexamined 15% of the measurements after 3 weeks.

The study provides the following parameters:

· Sagittal diameters or length of the FM: The maximum internal length of the FM along the midsagittal plane as distance between basion and opisthion.

· Transverse diameter or width of the FM: The maximum internal width of the FM perpendicular to the midsagittal plane as the greatest width of the FM.

· Circumference of FM: Automatically given after tracing the bony margin of the FM on the CBCT image.

· Shapes of FM were determined and classified: egg-shaped, round, oval, tetragonal, pentagonal, hexagonal, irregular (A), and irregular (B) (Figure 2). They were previously used by Murshed et al. (21).

The age of the patients was categorized into five groups: 17–25, 26–35, 36–45, 46–55, and 56+ years old.

2.1. Data analysis

The data were statistically analyzed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA) for Windows. The mean values, standard deviations, and medians were calculated with descriptive statistics, and chi-square test and t-test were applied to assess the level of significance for sex and age. A P-value of 0.05 was considered as the level of significance. Intraobserver correlation was tested using the Bland–Altman test and Pearson correlation coefficients in evaluating the compliance of measurements made at different times in the measurement of morphological variables.

3. Results

In total 190 individuals (102 females, 53.7% and 88 males, 46.3%, mean age ± standard deviation: 46.8 ± 15.7) were examined. For each measurement, sagittal ad transverse diameters and the circumference of the FM were calculated in both males and females, with the maximum and minimum diameters, mean values, and standard deviations. The metric parameters are shown in Table 1. Statistically significant differences were found between males and females for all variables. All measurements including the means of sagittal and transverse diameters and circumference of the FM were greater in males than in females ($P < 0.05$).

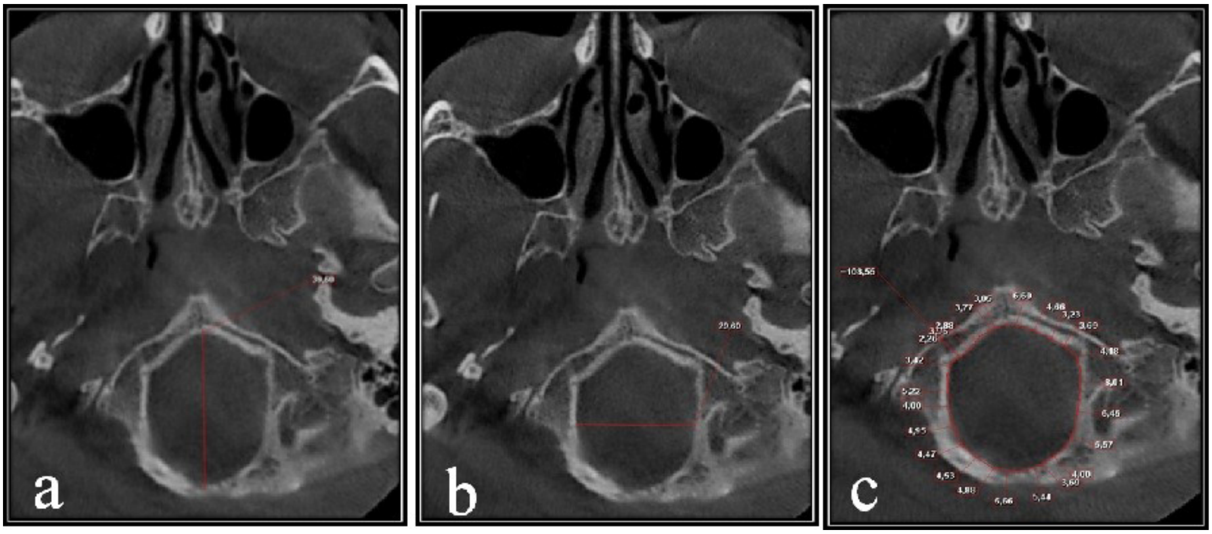

Figure 1. Sagittal diameters or length (a), transverse diameter or width (b), circumference of foramen magnum (c).

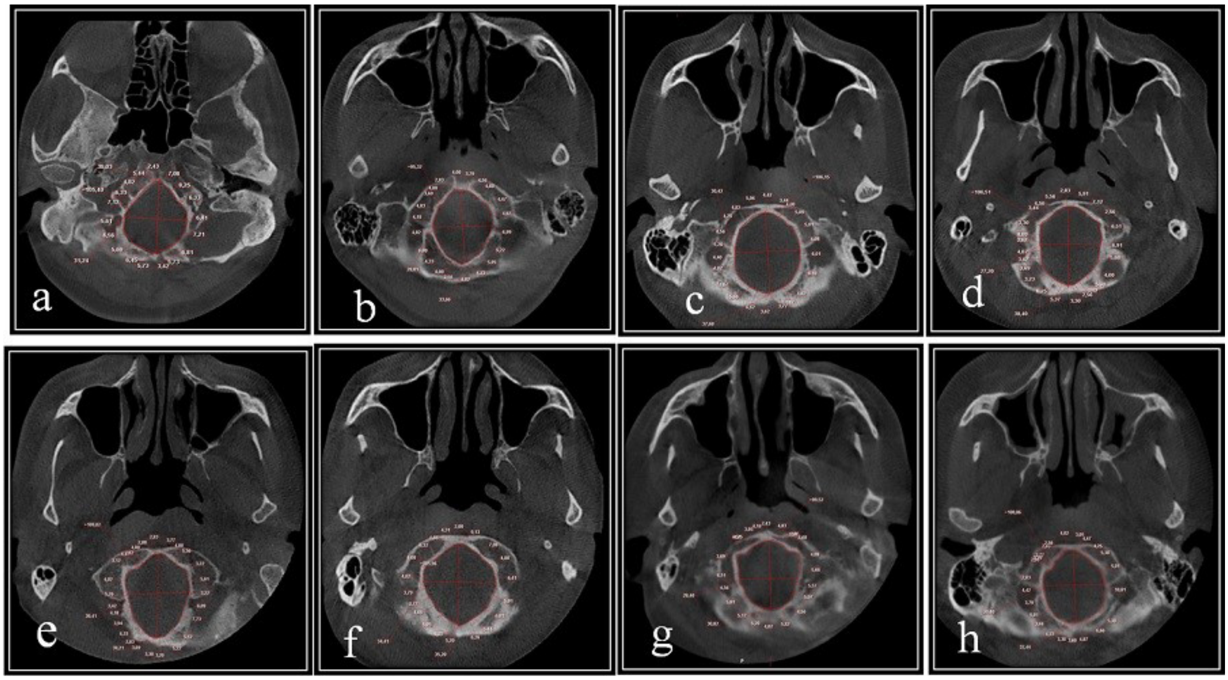

Figure 2. The shape of foramen magnum was classified as egg-shaped (a), oval (b), round (c), hexagonal (d), pentagonal (e), tetragonal (f), irregular A (g), and irregular B (h) on axial CBCT images.

Regarding the age groups, the majority of individuals were 56 years old or over (n = 63, 33.15%) and no statistically significant difference ($P > 0.05$) was found between the age groups (Table 2). There were no statistically significant differences ($P > 0.05$) between the age groups without sex difference for all variables (Table 3). Regarding the age groups of males (Table 4) and females (Table 5) no statistically significant difference ($P > 0.05$) was found for all variables.

Regarding the types of FM shapes, the most frequent type was found to be round (n = 41, 21.6%), while egg-shaped (n = 13, 6.8%) and tetragonal type (n = 15, 7.9%) were the least common (Table 6). No statistically significant difference was found between males and females for the types of FM (chi-square = 9.648, $P = 0.209$).

Pearson correlation coefficients were impeccable for intraobserver agreement. (Pearson correlation coefficients for sagittal diameter: 0.92, transverse diameter: 0.94,

Table 1. The maximum, minimum, means, standard deviations, and statistical analyses for FM parameters-sex comparative results.

Variables (mm)	Sex	N	Max. (mm)	Min. (mm)	Mean	Std. Deviation	T value	P-value
Sagittal diameter of FM	Female	102	41.6	27.2	34.66	2.31	–5.267	0.000*
	Male	88	40.4	31.2	36.43	2.32		
Transverse diameter of FM	Female	102	35.6	25.6	29.78	2.05	–4.547	0.000*
	Male	88	38.8	26.4	31.26	2.41		
FM circumference	Female	102	120.8	88.8	102.67	6.14	–5.759	0.000*
	Male	88	121.3	93.2	107.94	6.46		

*Difference is statistically significant $P < 0.05$ levels

circumference: 0.97). There was no significant difference between the measurements of the observer according to the Bland–Altman plots (Figure 3).

4. Discussion

Variability in the size and shape of the FM has been described by many studies in the literature (9,21,27,28). Catalina-Herrera et al. (13) revealed significant differences between males and females for sagittal and transverse diameters of the FM and the values of males were larger than those of females. Gapert et al. (16) demonstrated statistically significant differences between males' and females' skulls in FM dimensions using discriminant function and regression analysis in an eighteenth and nineteenth century British sample. In contrast, different studies have not found significant sexual dimorphism in the diameters of the FM (9,29). The aforementioned studies were performed with dry skulls. However, radiologic images provide several measurements without a flesh barrier and imaging methods are generally preferred by forensic scientists (6,20,21,24,30,31).

Several authors reported that radiologic measurements regarding FM are an objective assessment tool for sexual dimorphism (6,20–22). To the best of our knowledge, the majority of these studies were performed using helical CT, spiral CT, and temporal bone CT and there is only one study (24) performed via CBCT in the literature. Uysal et al. showed that the length and width of the condyle and width of FM diameters were larger in males than in females in a Turkish population. They found statistically significant differences between males and females for width of FM diameters (20), with accuracy of 81% in determination of sexual dimorphism. Murshed et al. (21) evaluated FM dimensions using spiral CT and found that sagittal and transverse diameters and also area of the FM were significantly greater in males than in females for a Turkish population. Uthman et al. (6) measured sagittal and transverse diameters, area, and circumference of the FM in an Iraqi population and reported that the examination of the FM on CT scans can provide valuable measurements and these images could be used for sexual dimorphism when other methods are inconclusive. Abdel-Karim et al. (22) revealed that the length and width of the FM are significantly larger in males than in females for an Egyptian population. Ilgüy et al. (24) found that the accuracy rate of FM measurements was 87.4% in females and 77.3% in males, with an overall accuracy rate of 83.2% on CBCT images in sex determination of a Turkish population. However, they also emphasized that transverse diameter and circumference of the FM cannot be reliable for sexual dimorphism; only the sagittal diameter of the FM seemed to be useful (24). In the present study, sagittal and transverse diameter and circumference of the FM were larger in males than in females, with a statistically significant difference. This result is in accordance with some previous reports (6,21,22), but different from the results published by Ilgüy et al. (24).

Murshed et al. (21) performed the measurements regarding FM dimensions on spiral CT scans and recorded the means of its sagittal and transverse diameters as 37.2 mm and 31.6 mm in males and 34.6 mm and 29.3 mm

Table 2. The distribution of age groups.

		n	%
Age group	17–25	23	12.11
	26–35	29	15.26
	36–45	29	15.26
	46–55	46	24.21
	56+	63	33.16
	Total	190	100.0

$P = 0.262$, Chi-square = 5.257

Table 3. The difference between age groups for all individual in parameters.

	Age group	Count	Mean	Standard deviation	Minimum	Maximum	Median	P	Significant differences
Sagittal diameter of FM	17–25	23	36	2.3	32.4	40.4	35.2	0.379	No
	26–35	29	36.1	2.1	31.6	39.6	36.0		
	36–45	29	35.2	2.3	32.4	40.4	35.2		
	46–55	46	35.1	2.7	27.2	39.6	34.8		
	56+	63	35.4	2.6	30.4	41.6	35.6		
Transverse diameter of FM	17–25	23	30.9	2.3	27.6	36.8	30.4	0.394	No
	26–35	29	31.1	2.0	26.8	34.0	31.2		
	36–45	29	30.4	2.6	25.6	38.8	30.0		
	46–55	46	30.1	2.1	26.0	35.6	30.0		
	56+	63	30.3	2.5	26.0	36.9	29.6		
FM circumference	17–25	23	106.9	6.7	94.3	121.3	106.0	0.191	No
	26–35	29	107.1	6.9	93.2	120.4	107.8		
	36–45	29	104.4	6.4	94.1	117.3	104.2		
	46–55	46	103.9	6.4	93.2	119.4	103.7		
	56+	63	104.8	7.1	88.8	120.8	104.1		

Table 4. The difference between age groups for man individual in parameters.

	Age group	Count	Mean	Standard deviation	Minimum	Maximum	Median	P	Significant differences
Sagittal diameter of FM	17–25	6	37.1	3.2	32.8	40.4	38.0	0.626	No
	26–35	12	37.2	1.5	35.2	39.6	37.4		
	36–45	14	36.5	2.1	33.2	40.4	36.4		
	46–55	24	36.1	2.5	32.0	39.6	35.6		
	56+	32	36.2	2.4	31.2	40.4	36.0		
Transverse diameter of FM	17–25	6	32.8	3.0	29.6	36.8	32.0	0.194	No
	26–35	12	31.9	1.9	28.8	34.0	32.4		
	36–45	14	31.9	2.6	28.8	38.8	31.6		
	46–55	24	30.5	2.0	26.4	33.6	30.8		
	56+	32	31.0	2.6	27.2	36.9	30.4		
FM circumference	17–25	6	112.1	6.5	103.9	121.3	112.3	0.165	No
	26–35	12	110.6	5.3	102.3	120.4	110.9		
	36–45	14	108.6	4.9	100.7	117.3	108.4		
	46–55	24	105.8	6.9	93.2	119.4	105.5		
	56+	32	107.5	6.7	93.3	117.7	107.8		

in females, respectively. Uthman et al. (6) used helical CT images for FM measurements and found mean values for the sagittal and transverse diameters of 34.9 mm and 29.5 mm in males and 32.9 mm and 27.3 mm in females, respectively. Uysal et al. (20) used temporal bone CT images reported the means of the FM's transverse diameter were 30.8 mm and 28.9 mm in males and females, respectively. In the same study, the means of its sagittal diameter were determined as 37 mm and 34.8 mm for males and females, respectively (20). Ilgüy et al. (24) reported that the sagittal

Table 5. The difference between age groups for female individuals in parameters.

	Age group	Count	Mean	Standard deviation	Minimum	Maximum	Median	P	Significant differences
Sagittal diameter of FM	17–25	17	35.6	1.9	32.4	40.1	35.2	0.104	No
	26–35	17	35.3	2.1	31.6	38.4	35.6		
	36–45	15	34.1	1.9	32.4	39.7	33.2		
	46–55	22	33.9	2.5	27.2	38.4	34.4		
	56+	31	34.6	2.5	30.4	41.6	34.4		
Transverse diameter of FM	17–25	17	30.2	1.6	27.6	32.8	30.4	0.137	No
	26–35	17	30.5	2.0	26.8	33.2	30.8		
	36–45	15	29.1	1.7	25.6	32.4	29.2		
	46–55	22	29.7	2.1	26.0	35.6	29.6		
	56+	31	29.5	2.3	26.0	35.6	29.2		
FM circumference	17–25	17	105.1	6.0	94.3	117.3	104.6	0.102	No
	26–35	17	104.6	7.0	93.2	115.6	106.3		
	36–45	15	100.5	5.0	94.1	114.3	99.5		
	46–55	22	101.8	5.2	95.0	111.6	101.8		
	56+	31	101.9	6.5	88.8	120.8	100.9		

Table 6. Types of FM shape - number of cases and percentages to sex.

			Sex		Total	%
			Female	Male		
Evaluation of FM-sectional shape	round	n	21	20	41	21.6
	hexagonal	n	14	21	35	18.4
	oval	n	11	13	24	12.6
	egg-shaped	n	9	4	13	6.8
	tetragonal	n	11	4	15	7.9
	pentagonal	n	9	9	18	9.5
	irregular (A)	n	18	8	26	13.7
	irregular (B)	n	9	9	18	9.5
Total		n	102	88	190	100.0

Chi-square = 9.648, P = 0.209

and transverse diameter means of the FM were 37.8 mm and 32.7 mm and 35.6 mm and 31.1 mm in males and females, respectively, on CBCT images. In the present study, the mean values of its sagittal diameter were 36.4 mm for males and 34.6 mm for females. The means of its transverse diameter were 31.2 mm and 29.8 mm in males and females, respectively. Our results were very similar to those of previous studies (6,20,21,24).

In the literature, there is a limited number of studies about the measurement of FM circumference (6,16,24). Previous studies have reported that the means of FM circumference were 99.3 mm and 108.1 mm for males and its mean values were 92.6 mm and 102.2 mm for females on helical CT and CBCT images, respectively (6,24). Another study performed on human skulls determined that the means of FM circumference were 99.07 mm in males and 95.65 mm in females (16). In the present study, the means of FM circumference were recorded as 107.9 mm and 102.7 mm in males and females, respectively, and a statistically significant difference was found between

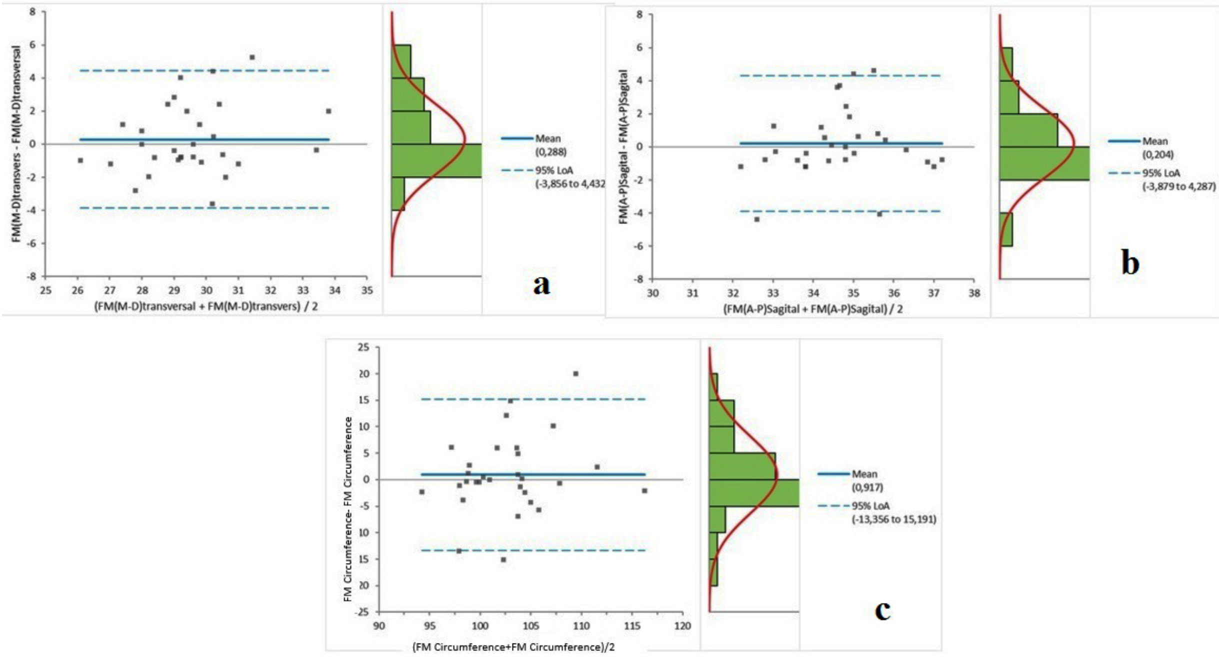

Figure 3. Bland–Altman plot for transverse diameter of FM (a), Bland–Altman plot for sagittal diameter of FM (b), Bland–Altman plot for circumference of FM (c).

the sexes. These results were very similar to the results reported by Ilgüy et al. (24) and each of two studies findings' were overestimated. This condition may be related to either the use of the same imaging method (CBCT) or racial similarities of the study samples in both of them.

The shape of the FM is variable and remains controversial in previous studies performed in different populations (21,27,28,30,32). The most common shape of the FM has been reported as oval (68%) in Indian dry skulls (27); round in a Turkish population (21.8%) (21), in Turkish populations (18.8%) (30), and dry skulls of an Indian population (22.6%) (32); and tetragonal in dry adult skulls obtained from a Turkish population (28) (25.66%). In the present study, the round type was the most common, in 21.6% of the patients. The round type was commonly observed in females and hexagonal type was the most common FM shape in males. However, there was no statistically significant difference between males and females for FM shape. The differences among the results of studies might result from racial differences or visualization of the examination techniques.

In conclusion, the results of this study show that CBCT images can provide valuable information regarding FM and the measurements of its sagittal and transvers diameters and also its circumference may be reliably used for sexual dimorphism in anthropometric analysis and forensic medicine.

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