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Shape Analysis and Morphometric Evaluation of the Obturator Foramen in Dry Human Bones

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ABSTRACT

Purpose: This study aims to analyze the shape and morphometric features of the obturator foramen (OF) in dry human bones.

Methods: Forty-six (Right:15, Left:31) dry human coxal bones were evaluated. Photographs of samples for morphometric measurements were taken using a transparent osteometric box (TOB) designed for this study. Horizontal and vertical diameters of OF were measured according to two different principles. Measurements were taken to determine the localization of OF on the coxal bone (hip bone) relative to the acetabulum, pubis, and ischium. Shape analysis (visual classification) of OF was performed with the conventional method. In order to examine the shape variations of the OF in more detail, quantitative shape analysis based on Elliptic Fourier Analysis was performed with the SHAPE software.

Results: A significant difference was observed between the diameter measurements obtained by the two methods ($p<0,001$). After the qualitative shape analysis 6 types were determined in the qualitative shape analysis (oval, ellipsoid, piriform, trapezoidal, triangular, and atypical). Researchers agreed on the shape types of 16 bones. Quantitative shape analysis revealed 77 principal components (PC). The first nine significant PC explained the variation in the shape of OF cumulatively by 92,61%.

Conclusion: The standard position, defined for the first time in this study, is recommended as an easy-to-reproduce position for dry bone measurements or radiological morphometric studies. The conventional shape analysis method (visual typing) is not capable of sufficient evidence-based discrimination. Therefore, examining the shape features of OF based on quantitative findings such as Elliptic Fourier Analysis may yield more accurate results.

Keywords: Obturator foramen; Hip bone; Morphometry; Morphology; Elliptic Fourier Analysis; Principal Component Analysis

Kuru İnsan Kemiklerinde Foramen Obturatum'un Morfometrik Özellikleri ve Şekil Analizi

ÖZET

Amaç: Bu araştırmanın amacı foramen obturatum'un (FO) detaylı morfometrik ve morfolojik şekil analizinin yapılmasıdır.

Yöntem: Çalışmada 46 (sağ:15, sol:31) adet kuru os coxae incelenmiştir. Morfometrik ölçümlerde bu çalışma için tasarlanmış şeffaf osteometrik kutu kullanılarak standart bir pozisyon belirlenerek örneklerin fotoğrafları alınmıştır. FO'nun iki farklı prensibe göre horizontal ve vertikal çapları ölçülmüştür. FO'nun os coxa üzerindeki lokalizasyonun acetabulum'a, pubis'e ve ischium'a göre belirlenmesi için ölçümler alınmıştır. FO'nun konvansiyonel yöntemle şekil analizi (görsel tiplendirme) yapıldı. FO'nun şekil varyasyonlarının daha ayrıntılı incelenmesi için SHAPE yazılımı ile Eliptik Fourier Analizi temeline dayanan kantitatif şekil analizi yapılmıştır.

Bulgular: İki farklı yöntemle elde edilen çap ölçümleri arasında anlamlı farklılık bulunmaktadır ($p<0,001$). Kalitatif şekil analizinde 6 görsel tip tespit (oval, elips, piriform, yamuk, üçgen, atipik) edilmiştir. Araştırmacılar 16 kemiğin şekil tipi üzerinde mutabık kalmışlardır. Kantitatif şekil analizinde 77 temel bileşen (TB) ortaya çıkmıştır. İlk 9 anlamlı TB, FO'nun şeklindeki varyasyonu kümülatif olarak %92,61 oranında açıklamaktadır.

Sonuç: İlk kez bu çalışma ile tanımlanıp kullanılan standart pozisyon ile, kuru kemiklerde veya radyolojik morfometrik çalışmalar için literatüre standardize edilmesi kolay ve tekrarlanabilir bir pozisyon önerilmektedir. Konvansiyonel şekil analiz yöntemi (görsel tiplendirme) yeterli düzeyde kanıta dayalı diskriminasyon gücünde değildir. Bu nedenle FO'nu şekil özelliklerini Eliptik Fourier Analizi gibi kantitatif bulgulara dayanarak incelemek daha doğru sonuçlar verebilir.

Anahtar Kelimeler: Foramen obturatum; Coxa; Pelvis; Morfometri; Morfoloji; Eliptik Fourier Analizi, Temel Bileşen Analizi

The ilium, ischium, and pubis begin to fuse at 14-16 years of age and become a single bone and form the coxal bone (hip bone). The obturator foramen (OF) formed by the pubis and ischium is a structure with clinical and anthropometric importance. Especially the hip bone is one of the bones that allows us to reach reliable and accurate results in sex determination in anthropology (1). In the literature, the morphological features of OF have been examined together with other anatomical structures belonging to coxal bone (2, 3). There are studies investigating the dimorphic feature of OF according to gender (4). It has been reported that it is larger and oval in shape in men, and smaller and triangular in women (4). Morphometric details and shape type characteristics of OF can provide helpful information in forensic science, such as sex and age determination (5, 6). In addition to anthropological research, OF and surrounding anatomical structures are essential in clinical anatomy. In surgical procedures performed in this region (such as transobturator band placement, obturator nerve blockage, obturator bypass, tumor surgery, hernia repair, and traumas), care should be taken against the vascular structures (7-9). Considering the anatomical structure of OF and the morphometric relationship of the anatomical structures of the OF may reduce the risk of injuries to the neurovascular structures within the obturator canal during the procedures like surgical treatment of the urinary incontinence (8).

In the literature, it seems that the morphological features of OF have not been revealed in sufficient detail. Methodological standardization inconsistencies or uncertainties regarding morphometric methods for OF have also been observed. More detailed analysis of the morphological features of OF may lead to more successful results in areas such as sex or age determination. Based on these reasons, our research aimed to make a detailed morphometric/morphological analysis of OF. In this research, morphometric measurements were taken based on anthropometric points on the acetabulum, pubis, and ischium. The location of the OF on the coxal bone and its relations with the bone structures were examined. In addition, qualitative shape analysis and quantitative shape analysis based on the Elliptic Fourier method were used to explain the shape properties of OF.

Material and Method

Dry bone collection of the department of anatomy was evaluated. Coxal bones with any deformation in the OF were excluded. Forty-six (Right: 15, Left: 31) dry coxal bones were included in the study. There are no demographic documents such as age, gender, or cause of death of the donors of the bones. Right and left coxal bones are independent bones. They do not belong to the same individual. Institutional ethics committee approval was obtained prior to this study.

General Morphometric Measurements of the Coxal Bones

A digital caliper was used to measure the height and width of the coxal bones. The distance between the lowest point of the ischial tuberosity and the highest point of the iliac crest was measured for height. The distance between the anterior superior iliac spine and posterior superior iliac spine was measured for width (10).

Standard Position for Photograph in Morphological Evaluation

In our study, photographs of the hip bones were taken in a standard position. Canon 800D camera was used for photography. The studio environment used for taking photographs and the transparent osteometric box (TOB) designed for standardization of the position for photography are presented in Figure 1. In the photographing setup, spirit levels, bone landmarks, and a TOB were used to provide imaging standardization based on the principal plane and axes (Figure 1a). The movements of the bones depending on the planes and their rotation due to the axes are prevented. The TOB is made of transparent mica (Figure 1b). The TOB has a cubic design with six equal surfaces perpendicular to each other. (Figure 1c). The standard position description for photography is presented in Figure 2, accompanied by a visual.

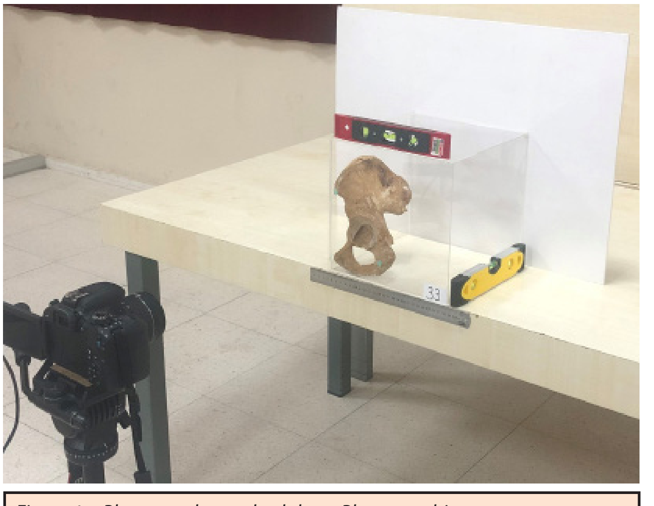


Figure 1a. Photography methodology. Photographing setup

Figure 1b. Photography methodology. Transparent Osteometric Box (TOB)

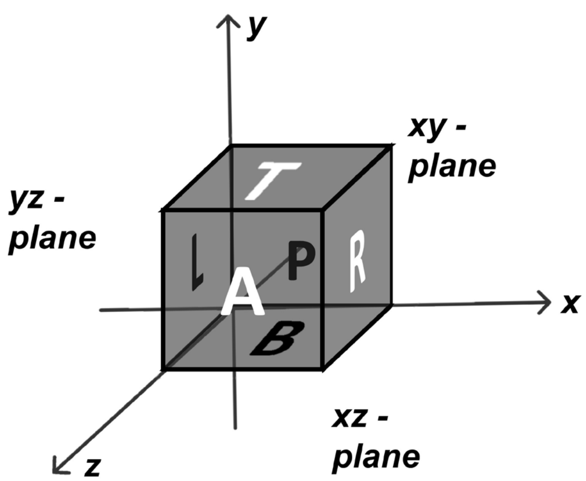


Figure 1c. Photography methodology. Design of the TOB. Surfaces of the TOB: Anterior (A), posterior (P), right (R), left (L), top (T), bottom (B)

Morphometric Evaluation of Obturator Foramen

ImageJ (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, https://imagej.nih.gov/ij, 1997–2018) software was used for measurements on photographs of hip bones.

Morphometric Landmarks and Measurements Regarding the Obturator Foramen

The landmarks and descriptions of morphometric measurements related to OF are presented in Figure 3. SHAPE v.1.3 software was used to measure the area of the OF (11).

Morphometric Landmarks and Measurements Regarding the Localization of the Obturator Foramen on the Coxal Bone

The landmarks and descriptions of morphometric measurements related to the localization of OF on the coxal bone are presented in Figure 3.

Shape Analysis

Qualitative Shape Analysis of Obturator Foramen

In the current study, conventional shape analysis (visual typing) was performed first for the shape typing of OF. Qualitative shape analysis (visual typing) was performed on photographs taken in standard position (Figure 2). Visual typing is based on OF's analogy to any geometric shapes. All photos have been reviewed several times. Then the geometric shape that each OF resembles was noted. In this preliminary examination, it was observed that five geometric models (shape types) were dominant. Then, OFs were re-evaluated and included in the appropriate type group. The atypical group was created for shapes that do not fit any typing. The dominant geometric models (shape types) determined for OF are presented in Figure 4.

Quantitative Shape Analysis of Obturator Foramen

In order to reveal the variations in the shape structure of the OF in more detail, a quantitative shape analysis based on Elliptic Fourier Analysis (EFA) was performed. SHAPE v.1.3 software was used for quantitative shape analysis of OF (11). EFA conducted by SHAPE seeks patterns in the expression of the shape and presents them as principal component analysis (PCA) findings. PCA detects the individual-to-individual variation in the shape by identifying the principal components (PC) (11). Elliptic Fourier Analysis (EFA) is a numerical method that allows the outline of a shape to be comprehensively measured and described (6). In addition, the SHAPE software ranks these PCs in decreasing order of importance; The first PC explains the most significant part of the shape variance, while the subsequent PCs explain less. For each of the PCs, a single numerical PC score is generated that describes the shape characteristics of that sample. The SHAPE software also creates a drawing of each PC in the sample, allowing the researcher to observe how that aspect of the shape changes across its endpoints. The mean shape of a significant PC is given as the reference point, and shapes within ±2 standard deviations from the mean shape are also produced (12). In order to perform the quantitative shape analysis of the OF, the OF images in the position described in Figure 2 were transferred to the SHAPE software after processing with the technical adjustments required by the software. As a result, EFA with the SHAPE software provided the PCs that affect the shape variation and the contribution ratios of PCs to the shape variation.

Figure 2. Standard photography position

Description of the standard position of photography:

- Anterior superior iliac spine (ASIS) (short black arrow, #1), the most lateral point of the ischial tuberosity (long black arrow, #2), and pubic tubercle (short white arrow, #3) are fixed on the A surface of the transparent osteometric box (TOB)
- ASIS (short black arrow, #1) and the most superior point of the articular surface of the pubic symphysis (long white arrow, #4) are fixed on the L surface of the TOB
- The optical axis of the camera is perpendicular to the A surface of the TOB and traverses through the center of the obturator foramen (OF)
- The center of the lens of the camera is fixed 30 cm away from the borders of the OF

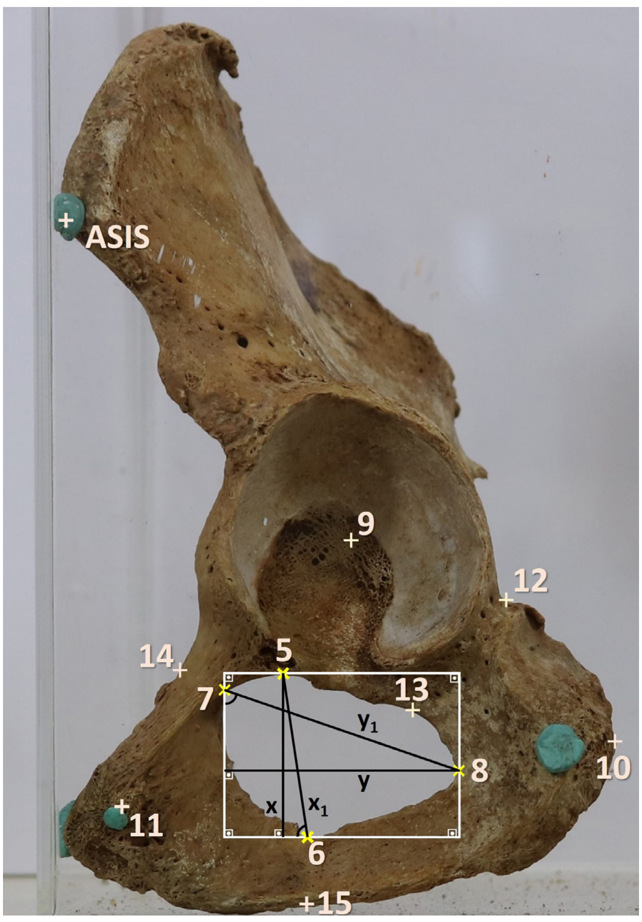


Figure 3. Osteometric landmarks and measurements on the left coxal bone

Osteometric Landmarks:

#5: The most superior point of the OF
#6: The most inferior point of the OF
#7: The most anterior point of the OF
#8: The most posterior point of the OF
#9: the intersection of the vertical and horizontal diameters of the acetabulum
#10: The most posterior point of the ischial tuberosity
#11: pubic tubercle
#12: The closest point to the margin OF located on the posterior aspect of the ischium
#13: The intersection point of the "margin of the OF" and "the perpendicular line from the #12 to the margin of the OF."
#14: The intersection point of "the pecten pubis (pectineal line)" and "the perpendicular line from the #7 to the pecten pubis (pectineal line)."
#15: The intersection point of the "lower border of the ischiopubic ramus, and "the perpendicular line from the #6 to the lower border of the ischiopubic ramus."
ASIS: Anterior Superior Iliac Spine

Morphometric Measurements:

A. Measurements regarding the OF

a) Vertical diameter measurements of OF
i) The direct distance between the most superior and the most inferior points of the OF (x1, between #5 and #6)
ii) The vertical distance between the tangents of the #5 and #6 (x, between #5 and the horizontal line traversing the #6)
b) Horizontal diameter measurements of OF
i) The direct distance between the most anterior and the most posterior points of the OF (y1, between #8 and #7)
ii) The horizontal distance between the tangents of the #8 and #7 (y, between the #8 and the vertical line traversing the #7)
c) Measurements regarding the thickness of the bony structures surrounding the OF
i) Distance from OF to Ramus of the ischium (between #12 and #13)
ii) Distance from the most anterior point of OF to Superior pubic ramus (between #7 and #14)
iii) Distance from the most inferior point of OF to ischiopubic ramus (between #6 and #15)

B. Measurements Regarding the Localization of the Obturator Foramen on the Coxal Bone

a) Measurements representing the morphometric relationship with the acetabulum
i) Distance from acetabulum to the most anterior point of OF (between #9 and #7)
ii) Distance from acetabulum to the most posterior point of OF (between #9 and #8)
iii) Distance from acetabulum to the most superior point of OF (between #9 and #5)
iv) Distance from acetabulum to the most inferior point of OF (between #9 and #6)
b) Measurements representing the morphometric relationship with the ischium
i) Distance from ischial tuberosity to the most anterior point of OF (between #10 and #7)
ii) Distance from ischial tuberosity to the most posterior point of OF (between #10 and #8)
iii) Distance from ischial tuberosity to the most superior point of OF (between #10 and #5)
iv) Distance from ischial tuberosity to the most inferior point of OF (between #10 and #6)
c) Measurements representing the morphometric relationship with the pubis
i) Distance from the pubic tubercle to the most anterior point of OF (between #11 and #7)
ii) Distance from the pubic tubercle to the most posterior point of OF (between #11 and #8)
iii) Distance from the pubic tubercle to the most superior point of OF (between #11 and #5)
iv) Distance from the pubic tubercle to the most inferior point of OF (between #11 and #6)

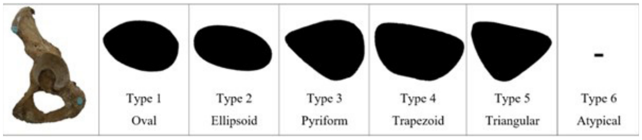
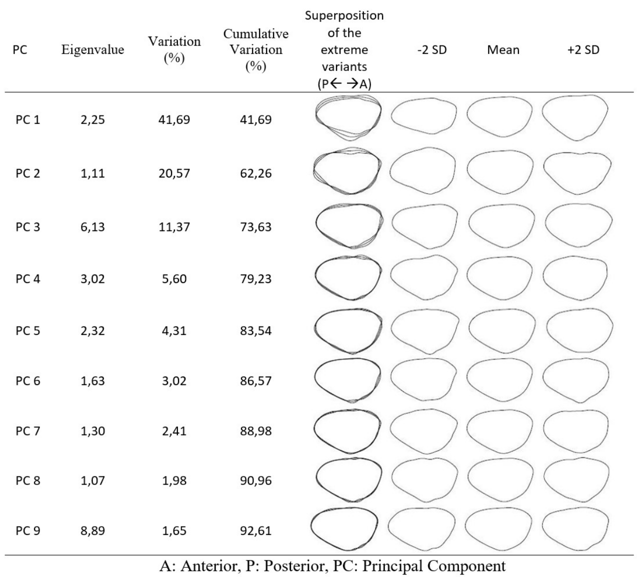


Figure 4. Visual types of obturator foramen detected by qualitative shape analysis



PC	Eigenvalue	Variation (%)	Cumulative Variation (%)	Superposition of the extreme variants (P← →A)	-2 SD	Mean	+2 SD
PC 1	2,25	41,69	41,69				
PC 2	1,11	20,57	62,26				
PC 3	6,13	11,37	73,63				
PC 4	3,02	5,60	79,23				
PC 5	2,32	4,31	83,54				
PC 6	1,63	3,02	86,57				
PC 7	1,30	2,41	88,98				
PC 8	1,07	1,98	90,96				
PC 9	8,89	1,65	92,61				

A: Anterior, P: Posterior, PC: Principal Component

Figure 5. Principal component analysis (PCA) for the shape of the obturator foramen (n=46)

Statistical Analysis

Statistical analyzes of the study were carried out with the IBM SPSS Statistics 25.0 (IBM Corp., Armonk, New York, USA). Descriptive statistics of the variables in the study, number of units, minimum value, maximum value, and mean±standard deviation (Mean±SD) values were presented. The distribution characteristics of the data were investigated with the Shapiro-Wilk test. All the data obtained by the measurements meet the parametric test assumptions. Side comparisons were examined with the independent samples T-test since the right, and left side bones did not belong to the same individual. Cohen's Kappa coefficient was used for the agreement of observers about the qualitative shape analysis findings. The statistical significance level was accepted as α=0.05.

Results

General Morphometric Measurements of the Coxal Bones

Depending on the deformations in coxal bones, measurements were taken from 44 samples for height and 34 for width. General morphometric variables of coxal bones are presented in Table 1. There was no statistically significant difference between the right and left sides for both height and width variables.

Morphometric Evaluation of Obturator Foramen

Measurements Regarding the Obturator Foramen

Measurements related to OF are presented in (Table 2). There were significant differences between the findings retrieved with different diameter measurements. "The direct distance between the most superior and the most inferior points of the OF (x1, distance between #5 and #6)" is significantly higher than the "The vertical distance between the tangents of the #5 and #6 (x, distance between #5 and the horizontal line traversing the #6)" (p<0,001, Table 2). "The direct distance between the most anterior and the most posterior points of the OF (y1, distance between #8 and #7)" is significantly higher than the "The horizontal distance between the tangents of the #8 and #7 (y, distance between the #8 and the vertical line traversing the #7)" (p<0,001, Table 2). The distance "from the most inferior point of OF to ischiopubic ramus (between #6 and #15)" was significantly higher on the left than on the right.

The area of OF was determined by SHAPE as 1072,68±170,97 (n:46) mm². There was no statistically significant difference between right side measurements [1123,30±207,24 (n:15)] and left side measurements [1048,19±148,00 (n:31)].

Measurements Regarding the Localization of the Obturator Foramen on the Coxal Bone

The findings of the variables representing the localization of OF are presented in Table 3. There was a statistically significant difference between the parties for the variable "Distance from acetabulum to the most superior point of OF (between #9 and #5)" (p<0,05, Table 3).

Shape Analysis

Qualitative Shape Analysis Results of Obturator Foramen

OF was assigned to 5 geometric model (shape types) types by two researchers. Those that could not be assigned to a particular geometric model were typed as atypical. The qualitative typing decisions of the two researchers and the number of cases they agreed and disagreed with are presented in Table 4. Cohen's Kappa coefficient was 0,50.

Table 1. General morphometric variables of the coxal bones (mm)

Variable	Side	n	Min	Max	Mean±SD	p*
Height of the coxal bones	Right	14	177,04	220,00	201,10±12,94	0,243
	Left	30	176,57	229,71	205,97±12,57	
	Total	44	176,57	229,71	204,42±12,75	
Width of the coxal bones	Right	10	128,16	169,01	151,11±12,57	0,854
	Left	24	125,49	172,34	150,33±10,64	
	Total	34	125,49	172,34	150,56±11,05	

** Independent samples T-test (comparison of the right and left sides)*

Table 2. Measurements regarding the obturator foramen (OF) (n=46, mm).

Variable (Measurement)	Side	n	Min	Max	Mean±SD	p*
Vertical diameter measurements of OF						
The direct distance between the most superior and the most inferior points of the OF (x1, between #5 and #6)	Right	15	30,28	47,18	37,69±4,25	0,702
	Left	31	26,35	46,55	37,15±4,46	
	Total	46	26,35	47,18	37,33±4,35 [a]	
The vertical distance between the tangents of the #5 and #6 (x, between #5 and the horizontal line traversing the #6)	Right	15	28,46	46,00	36,54±4,41	0,715
	Left	31	26,00	46,23	36,05±4,14	
	Total	46	26,00	46,23	36,21±4,19 [a]	
Horizontal diameter measurements of OF						
The direct distance between the most anterior and the most posterior points of the OF (y1, between #8 and #7)	Right	15	43,65	58,95	50,62±3,79	0,794
	Left	31	43,86	57,45	50,32±3,58	
	Total	46	43,65	58,95	50,41±3,61 [b]	
The horizontal distance between the tangents of the #8 and #7 (y, between the #8 and the vertical line traversing the #7)	Right	15	40,38	58,80	47,99±4,81	0,902
	Left	31	40,70	55,38	47,83±3,55	
	Total	46	40,38	58,80	47,88±3,95 [b]	
Measurements regarding the thickness of the bony structures surrounding the OF						
Distance from OF to Ramus of the ischium (between #12 and #13)	Right	15	25,08	33,10	29,08±2,39	0,211
	Left	31	24,95	35,55	30,16±2,82	
	Total	46	24,95	35,55	29,80±2,71	
Distance from the most anterior point of OF to Superior pubic ramus (between #7 and #14)	Right	15	11,20	19,18	15,91±2,14	0,822
	Left	31	10,25	21,78	16,11±3,13	
	Total	46	10,25	21,78	16,04±2,82	
Distance from the most inferior point of OF to ischiopubic ramus (between #6 and #15)	Right	15	8,75	15,34	11,60±2,14	0,024
	Left	31	8,47	18,16	13,33±2,43	
	Total	46	8,47	18,16	12,77±2,46	

** Independent samples T-test (comparison of the right and left sides)*
[a] Significant difference between the findings of two vertical diameter measurement methods of OF (p<0,001).
[b] Significant difference between the findings of two horizontal diameter measurement methods of OF (p<0,001

Table 3. Measurements regarding the localization of the obturator foramen (OF) on the coxal bone (n=46, mm)

Variable (Measurement)	Side	n	Min	Max	Mean±SD	p*
Measurements representing the morphometric relationship with the acetabulum						
Distance from acetabulum to the most anterior point of OF (between #9 and #7)	Right	15	36,40	57,70	45,18±6,86	0,811
	Left	31	38,08	56,12	45,59±4,66	
	Total	46	36,40	57,70	45,45±5,40	
Distance from acetabulum to the most posterior point of OF (between #9 and #8)	Right	15	47,50	61,34	54,78±4,05	0,530
	Left	31	45,00	62,27	55,60±4,17	
	Total	46	45,00	62,27	55,33±4,11	
Distance from acetabulum to the most superior point of OF (between #9 and #5)	Right	15	28,68	34,94	31,63±2,10	0,028
	Left	31	26,99	40,83	33,65±3,09	
	Total	46	26,99	40,83	33,00±2,94	
Distance from acetabulum to the most inferior point of OF (between #9 and #6)	Right	15	57,61	72,12	65,29±4,45	0,492
	Left	31	55,60	77,21	66,28±4,58	
	Total	46	55,60	77,21	65,96±4,52	
Measurements representing the morphometric relationship with the ischium						
Distance from ischial tuberosity to the most anterior point of OF (between #10 and #7)	Right	15	68,58	91,67	77,97±5,77	0,210
	Left	31	70,04	87,00	79,85±4,10	
	Total	46	68,58	91,67	79,23±4,73	
Distance from ischial tuberosity to the most posterior point of OF (between #10 and #8)	Right	15	27,20	38,95	31,56±2,96	0,465
	Left	31	27,57	37,21	32,17±2,47	
	Total	46	27,20	38,95	31,97±2,62	
Distance from ischial tuberosity to the most superior point of OF (between #10 and #5)	Right	15	52,81	81,26	66,84±6,78	0,365
	Left	31	53,71	81,71	68,90±7,32	
	Total	46	52,81	81,71	68,23±7,14	
Distance from ischial tuberosity to the most inferior point of OF (between #10 and #6)	Right	15	58,73	80,81	65,83±5,50	0,228
	Left	31	53,11	74,32	63,96±4,54	
	Total	46	53,11	80,81	64,57±4,89	
Measurements representing the morphometric relationship with the pubis						
Distance from the pubic tubercle to the most anterior point of OF (between #11 and #7)	Right	12	17,76	33,70	28,97±4,73	0,207
	Left	26	20,94	39,96	31,38±5,65	
	Total	38	17,76	39,96	30,62±5,43	
Distance from the pubic tubercle to the most posterior point of OF (between #11 and #8)	Right	12	62,93	75,96	71,49±4,26	0,229
	Left	26	66,01	86,20	73,59±5,18	
	Total	38	62,93	86,20	72,93±4,95	
Distance from the pubic tubercle to the most superior point of OF (between #11 and #5)	Right	12	28,29	49,39	43,87±5,52	0,403
	Left	26	34,31	54,26	45,48±5,41	
	Total	38	28,29	54,26	44,97±5,42	
Distance from the pubic tubercle to the most inferior point of OF (between #11 and #6)	Right	12	37,41	46,82	42,73±2,95	0,170
	Left	26	34,29	64,28	45,45±6,39	
	Total	38	34,29	64,28	44,59±5,64	

** Independent samples T-test (comparison of the right and left sides)*
Descriptions of the landmarks are presented in Figure 3

Table 4. Qualitative analysis of obturator foramen (OF). Researchers' agreement and consistency in visual typing (n, %)

		2nd Researcher						
		Oval	Ellipsoid	Pyriform	Trapezoid	Triangular	Atypical	Total
1st Researcher	Oval	4*	0	1	3	0	2	10 (21,7)
	Ellipsoid	7	1*	0	1	0	3	12 (26,1)
	Pyriform	2	0	3*	3	0	1	9 (19,6)
	Trapezoid	1	0	0	1*	0	0	2 (4,3)
	Triangular	1	0	0	3	7*	0	11 (23,9)
	Atypical	1	0	0	1	0	0*	2 (4,3)
	Total	16 (34,8)	1 (2,2)	4 (8,7)	12 (26,1)	7 (15,2)	6 (13,0)	46 (100,0)

** Number of the cases in which the researcher agreed on a particular type*

Quantitative Shape Analysis Results of Obturator Foramen

In the quantitative shape analysis of OF, 77 PCs were identified that explained the shape variation of OF. The PCs that had a significant effect on the shape of the OF are presented in Figure 5. The first nine significant PCs presented in Figure 5 explain the variation in the shape of the OF cumulatively at a rate of 92,61%. PC 1 has the most significant influence on explaining the variation of shape. PC 1 explains 41,69% of the variation in shape (Figure 5).

Discussion

Clinical anatomical evaluation of OF is essential regarding the neurovascular structures passing through it and the anatomical structures neighboring it. Morphometric data of OF can guide clinicians in procedures such as transobturator tape placement, obturator nerve blockade, and obturator bypass surgery (7-9). The femoral head may penetrate the OF in orthopedic conditions such as hip dislocation (13, 14). Morphometric evaluation of OF may increase surgical restoration's success in treating such traumatic problems (13, 14).

In forensic science or anthropology, sex determination is a greater problem in skeletal remains with missing bone structures than in whole skeletons (15). In such cases, the smallest bone fragment obtained would be expected to give any clue for identification. The pelvis is considered one of the most reliable bones for sex determination relative to other bones in the body. The characteristic morphology of the human pelvis, like many bones of the human skeleton, may differ in gender, age, and race (15-17). Although most of the sexual dimorphism of the pelvis is explained by size differences, the gender-related shape variation is also very striking (15). It cannot be accepted as an allometric result of differences in body measurements between the sexes (15). From this perspective, examining the FO as a major pelvis structure can yield evidence-based findings in anatomical, anthropological, and forensic sciences.

Explanation of skeletal system morphology with numerical data enables researchers to perform repeatable, objective, and structured tests. For this purpose, it has been tried to explain the shape variations in the skeletal system using the SHAPE software. SHAPE outputs consist of PCs and images related to the shape variation. There are reports using this software in the literature (5, 12, 18, 19).

The coxal bone is irregular and partially flat. Morphometric studies require measurements of the hip bone in a standard position for consistency and reproducibility. We could not reach sufficiently detailed and confidently reproducible position descriptions for morphometric measurements of an irregular bone such as coxal bone (10, 20-23). In our study, a reproducible standard photographic position was tried to be achieved by preventing rotation in three axes for the coxal bone. It is considered that measurement variability will be high in studies where the standard photographing method or measurement position is unclear. The landmarks used in the measurements of such studies may vary depending on the position of the bone in the three-dimensional environment. Methodologic standardization will increase reliability and reproducibility for both landmarks and measurements.

Since tools such as 3D (three-dimensional) digital modeling were not used in the methodology of this study, indirect measurements were taken on the projections of the axes and surfaces representing the three-dimensional environment. Pullanna et al. (24) used a three-sided osteometric board to measure the bone height of the hip bone. In some studies, reporting the measurements obtained using an osteometric board, the position description of the bone was unclear, although the landmarks were defined (15, 24-27). In the current study, the box design of Pullana et al. (24) was improved, and the TOB was designed such standard position and photographing could be made more accurately (Figure 1).

It is thought that the TOB used in this study may also be helpful for further research on bone morphology. Transverse, sagittal, and frontal planes and vertical, sagittal, and transverse axes were used to ensure the position standard of the coxal bone in the TOB. (Figure 1). In order to prevent the rotation of the coxal bone in 3 axes, the bone was fixed in at least two planes using selected anatomical landmarks (Figure 2). With this principle, hip bone measurements can be standardized. The standard position of our method for coxa can be considered a strong aspect of the work in terms of easy applicability and reproducibility. In terms of reproducibility, this feature of current research may contribute to the standardization of bone positions not only for dry bone research but also for radiological studies using the digitally 3D reconstructed views of the individuals.

While some studies in the literature have reported findings similar to ours regarding the general morphometric findings of the coxa bone, some findings are not similar to ours (3, 10, 15). The variability in these findings may be due to racial or regional differences.

In our study, the vertical (x, x1, Figure 3) and horizontal (y, y1, Figure 3) diameters of the OF were measured with two different parameters. There is a significant difference between the results obtained with these methods. ($p<0,001$, Table 2). Some values about OF diameters have been reported by studies in the literature (28-30). The differences in the findings in the literature may be due to the measurement of the variables in different or non-standardized positions. Non-standardized positions may cause the osteometric points evaluated on the OF to shift. Research can be conducted on whether different diameter measurement methods can be used interchangeably. Our significantly different findings suggest that the methodologic differences may affect the findings regarding the diameter.

There were no statistically significant differences between the sides regarding the area of the OF [right: 1123,30±207,24 (n:15) and left: 1048,19±148,00 (n:31)] (Table 2). In the measurements regarding the thickness of the bony structures surrounding the OF, a statistical difference was found between the sides in the variable "Distance from the most inferior point of OF to ischiopubic ramus (between #6 and #15)" (Table 2). Examining this variable with studies conducted in larger numbers of coxal bones or whole pelvises (right and left sides belonging to the same individual) may provide more reliable interpretations. Data on the area of the OF and the thickness of the surrounding bone structures may provide an opportunity for analysis in terms of reconstructive surgery. In addition to these, as a secondary research finding, it was observed that variables regarding the OF was positively correlated with general morphometric measurements of the coxal bone.

There are few studies on OF shape analysis in the literature. In these studies, OF was categorized by analogy to two main shapes (ellipse/oval and triangle) (2, 3). OF types created with these geometric shapes are considered dimorphic in terms of gender. The OF is smaller and triangular in women, while it is larger and closer to oval in men (4). It was a simple visual classification. Although it is based on subjective observation, the contribution of the use of the shape feature of the bone is undeniable in anthropometric studies.

In order to define the OF shape, two different shape analysis methods were applied in our study.

In the first method, OF is visually typed with the conventional method, which is seen frequently in the current literature (2-4). No more than two types (triangular and elliptical/oval types) were observed in previous studies (2-4). In the current study, besides the commonly used triangle and ellipse/oval types, different geometric shapes had to be used to classify according to the visual analogy principle. In the present study, three new types (piriform, trapezoidal, and atypical) were defined in addition to oval, elliptical, and triangular OF types. The Cohen's Kappa coefficient, which indicates the agreement of the two researchers about the shape types they assigned to the OFs, was determined as 0.50. This finding has been interpreted as a disagreement in terms of typing. While researchers only agreed on the same type in sixteen bones, there were differences in their opinions on thirty bones (Table 4). The low number of FOs agreed on the shape suggests that the perception of edges and corners in visual typing may reveal differences that may lead to scientific deviations. It is interpreted that the shape analysis performed with this method should be handled with more suspicion in terms of objectively defining the OF shape.

It is thought that the shape analysis method discussed above may not have sufficient evidence-based discrimination power. Thus, in our research, EFA, carried out through the SHAPE software, was preferred as the second shape analysis method. Studies that carry out shape analysis with the EFA method based on quantitative evidence are available in the literature (6, 12, 19, 31, 32).

In the present study, 77 PCs were obtained using the EFA method with SHAPE. However, the effect of 9 PCs with the highest effect and significance on the shape of OF can be identified (Figure 5). The images obtained from the SHAPE software show the digital (numerical) differences that can be detected visually but cannot be verbally described precisely (Figure 5). In this context, these variations, which can be noticed with the naked eye, are defined and interpreted as follows: PC1 predominantly explains the variation in the tapering of the three corners observed in the OF. Thus, the ovality or triangularity of the OF can be interpreted by evaluating PC1. PC2 describes the convexity/concavity characteristic of the acetabulum side of the OF. In addition, it may provide information about the rotation of the OF margin relative to the center on the ischium side. PC3 describes the convexity/concavity changes on the pubic side of the OF. The first 3 PCs cumulatively explain 73.63% of the shape variation. Since the percentage of effect on shape variation is reduced, it becomes challenging to verbally describe changes in shape in subsequent PCs. PC4 and PC7 explain the shape variation on the acetabular side. PC5, PC6 and PC9 explain the minimal shape variations on the pubic side. PC8 seems related to the shape variation both on the pubic and acetabular sides.

Few studies in the literature explain the shape of OF with EFA. Kilmer et al. (5) also detected nine significant PCs for shape variation in FO, as in our study. They stated that PC2 expresses variation around the pubis, while PC3 captures shape changes related to ovality or triangularity (5). This result shows that the level of variational effect of PC definitions and rankings on OF in different populations may be variable. Therefore, it should be considered that the shape variations of OF may also differ between races (5).

This study has some limitations. In our study, there is a lack of demographic information such as age, gender, race, low number of bones and pelvises that do not have integrity. Therefore, the evaluation of OF-related morphometric measurements and shape analysis data of OF has been limited. The materials and methods used in our study may yield more robust or comparable results in study populations with fewer limitations mentioned above.

Conclusion

As far as we know, the standard position used for the first time in this study for morphometric measurements is thought to have a high repeatable character. A repeatable and easy to standardize position is proposed for morphometric research on radiologic or dry bone specimens. The location of the OF on the coxal bone was described for the first time by morphometric measurements.

It was observed that the researchers who conducted this study could not reach an absolute consensus on OF's visual (qualitative) typing. In the quantitative shape analysis of OF, the shape of OF was expressed numerically, and variational analyzes were performed on the outline of the shape. The lack of demographic information on the bones we used in the study prevented us from deepening the quantitative analysis interpretations. Quantitative shape analyzes on dry bones, cadavers, or radiological images for which demographic information is known will likely provide more detailed, descriptive, and distinctive information about the shape of OF.

Declarations

Authors declare no conflict of interests.

Ethical Approval

Ethical approval from the Ethics Board of İzmir Kâtip Çelebi University (Turkey) was obtained before the commencement of the study [Decree date and number: 21.09.2021 and 390). Our research has been approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and all subsequent revisions.

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