ORIGINAL RESEARCH

A Morphological and Morphometric Analysis of the Human Acetabulum and Its Clinical Significance

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ABSTRACT

Background: The acetabulum is a critical anatomical structure of the human pelvis, serving as the socket of the hip joint where the head of the femur articulates. The study aimed to analyze the morphological and morphometric characteristics of the human acetabulum and evaluate its clinical significance in orthopedic and surgical applications.

Materials and Methods: This descriptive observational study was conducted on 90 dry human pelvic bones (45 right and 45 left) in the Department of Anatomy. Morphological parameters such as acetabular shape, presence of an acetabular notch, depth, and orientation were assessed. Morphometric analysis included measurements of acetabular diameter (transverse and vertical), depth, rim thickness, acetabular angle, and inter-acetabular distance. Measurements were taken using a digital verniercaliper and an osteometric board. Statistical analysis was performed using SPSS version 21.0, with a significance level of $p<0.05$.

Results: The most common acetabular shape was circular (39.00%), followed by oval (36.00%) and irregular (25.00%). The acetabular notch was present in 89.00% of cases. Moderate acetabular depth was the most frequent (51.00%), with deep (30.00%) and shallow (19.00%) types also observed. Acetabular anteversion was predominant (84.00%), while retroversion was seen in 16.00% of cases. Morphometric analysis showed the mean transverse diameter was 52.3 ± 3.2 mm (right) and 51.9 ± 3.1 mm (left), while the vertical diameter was 50.8 ± 2.9 mm (right) and 50.5 ± 2.8 mm (left). The inter-acetabular distance was recorded as 165.3 ± 5.8 mm. No significant differences were found between the right and left acetabula.

Conclusion: The study highlights significant variations in acetabular morphology and symmetry in morphometric parameters. These findings are crucial for prosthetic design, hip reconstruction, and surgical planning. The data provide valuable reference points for orthopedic surgeons and researchers involved in hip joint biomechanics and clinical interventions.

Keywords: Acetabulum, Morphometry, Hip Joint, Prosthetic Design,

INTRODUCTION

The acetabulum is a critical anatomical structure of the human pelvis, serving as the socket of the hip joint where the head of the femur articulates. This ball-and-socket joint provides stability and a wide range of motion necessary for various functional activities, including walking, running, and maintaining posture. Understanding the morphology and morphometry of the acetabulum is essential for medical professionals, particularly orthopedic surgeons, radiologists, and anatomists, as variations in its structure can influence clinical outcomes in hip-related disorders, prosthetic design, and surgical interventions.[1]The acetabulum is a concave, cup-shaped cavity located at the point where the three bones of the pelvis—the ilium, ischium, and pubis—fuse. Its shape, depth, and orientation determine the congruency and stability of the hip joint. Variations in acetabular dimensions and angles play a significant role in the pathogenesis of various orthopedic conditions, including developmental dysplasia of the hip (DDH), femoroacetabular impingement (FAI), osteoarthritis, and fractures. Additionally, the acetabular morphology has clinical implications in total hip arthroplasty (THA), where precise measurements are required to ensure proper prosthetic alignment and function.[2]The morphologic study of the acetabulum involves assessing its shape, contours, and structural integrity, while the morphometric study includes measuring various parameters such as acetabular diameter, depth, inclination, and anteversion. These measurements help in understanding the normal anatomical variations and deviations that may lead to pathological conditions. Differences in acetabular dimensions have been observed among different populations and ethnic groups, emphasizing the need for region-specific data for improved clinical application.Inorthopedic practice, the significance of acetabular morphology and morphometry extends beyond diagnosis and treatment planning. Accurate knowledge of acetabular dimensions is crucial for the design and placement of implants in hip replacement surgeries. Improper positioning of prosthetic components can lead to complications such as implant loosening, impingement, instability, and limited range of motion. Moreover, in trauma cases involving acetabular fractures, detailed morphometric analysis aids in preoperative planning and surgical reconstruction.[3]Advancements in imaging techniques, including computed tomography (CT) and magnetic resonance imaging (MRI), have facilitated precise evaluation of acetabular anatomy. Three-dimensional reconstruction and computer-assisted modeling allow for enhanced visualization, aiding in both clinical diagnosis and surgical procedures. These technologies have also contributed to the development of patient-specific implants and navigation-assisted surgeries, improving surgical accuracy and patient outcomes.Apart from orthopedic implications, acetabular morphology is also relevant in forensic anthropology and biomechanics. In forensic investigations, acetabular dimensions can provide valuable information in age and sex determination, aiding in human identification. From a biomechanical perspective, acetabular orientation and depth influence the load distribution across the hip joint, affecting an individual's gait pattern and susceptibility to degenerative changes.[4,5]Despite extensive research on the acetabulum, gaps remain in understanding the variations in its morphology and morphometry across different populations and age groups. Further studies incorporating diverse demographic data and advanced imaging techniques can enhance the existing knowledge, leading to improved diagnostic accuracy and therapeutic strategies.[6] The morphologic and morphometric study of the human acetabulum holds significant clinical relevance in orthopedic, forensic, and biomechanical fields. A comprehensive understanding of acetabular anatomy aids in diagnosing hip disorders, planning surgical interventions, designing prosthetic components, and improving patient outcomes. Continued research in this domain is essential to refine surgical techniques and develop personalized treatment approaches for hip-related conditions.

AIM & OBJECTIVES

The study aimed to analyze the morphological and morphometric characteristics of the human acetabulum and evaluate its clinical significance in orthopedic and surgical applications.

MATERIALS AND METHODS

Study Design

This is a descriptive observationalcross-sectional study conducted to analyze the morphological and morphometric characteristics of the human acetabulumand evaluate their clinical significance.

Study Population

A total of 90 dry human pelvic bones (45 right and 45 left acetabula) were examined. The bones were obtained from the Department of Anatomy,Kanti Devi Medical College, Hospital & ResearchCentre, Mathura, Uttar Pradesh, India ensuring adequate representation of adult skeletal structures.

Study duration:The study was carried out over a period of one year and ten monthsfrom March 2021 to December 2022.

Ethical Considerations

Approval from the Institutional Ethics Committee was obtained prior to the studyand the study adhered to the guidelines for research involving human specimens. Since the study involved dry bones without identifiable personal data, informed consent was not applicable.The specimens were selected based on the following inclusion and exclusion criteria:

Inclusion Criteria

- Intact adult human pelvic bones with well-preserved acetabula.
- Bones free from pathological deformities or fractures.
- Bones of known laterality (right or left side identified).

Exclusion Criteria

- Pelvic bones with evident deformities, fractures, or pathological changes.
- Bones with incomplete or eroded acetabular structures.
- Pelvic bones of unknown laterality.

Outcome Measures

- Morphological variations in acetabular shape.
- Morphometric parameters such as mean acetabular diameter, depth, and index.
- Comparative analysis between right and left acetabula.

Methodology

The morphological parameters assessed in this study included the shape of the acetabulum, presence of the acetabular notch, depth of the acetabulum, and its orientation. The shape of the acetabulum was categorized into circular, oval, or irregular based on visual assessment. The presence of an acetabular notch was carefully observed and recorded for each specimen. The depth of the acetabulum was subjectively classified as shallow, moderate, or deep to understand variations in acetabular concavity. The orientation of the acetabulum was evaluated to determine whether it exhibited anteversion or retroversion, which is crucial in clinical settings such as hip joint stability and prosthetic implantation.

For morphometric analysis, precise measurements were taken using a digital verniercaliper with an accuracy of 0.01 mm and an osteometric board to ensure standardization. The acetabular diameter was measured in both transverse and vertical directions, representing the maximum horizontal and vertical dimensions of the acetabulum. The acetabular depth was determined by measuring the perpendicular distance from the deepest point of the acetabulum to a straight line connecting the superior and inferior rims. Additionally, the acetabular rim thickness was recorded at three key points: anterior, posterior, and superior margins. The acetabular angle was measured using a goniometer to determine the inclination of the acetabulum, which plays a significant role in load transmission and joint mechanics. The acetabular index was calculated as the ratio of acetabular depth to diameter, providing an indicator of acetabular concavity. Furthermore, in paired pelvic specimens, the inter-acetabular distance, which is the distance between the centres of both acetabula, was measured to assess symmetry and anatomical variations.Data was recorded separately for the right and left acetabula to assess possible asymmetry.

STATISTICAL ANALYSIS

- Descriptive statistics (mean, standard deviation) were used for morphometric parameters.
- All measurements were systematically recorded and tabulated for further analysis.
- Statistical analysis was performed using SPSS software version 21.0, ensuring accuracy and reliability of the results. The collected data were analyzed in the context of anatomical variations, clinical significance, and implications for orthopedic and surgical interventions.
- Paired t-tests were applied to compare right and left acetabular measurements.
- A p-value <0.05 was considered statistically significant.

RESULTS

The present study assessed the morphological and morphometric characteristics of the acetabulum using 90 dry human pelvic bones.

Table 1: Morphological Parameters of Acetabulum

Shape	Right Acetabulum (n, %)	Left Acetabulum (n, %)	Total (n, %)
Circular	18 (40.00%)	17 (38.00%)	35 (39.00%)
Oval	16 (35.00%)	17 (37.00%)	33 (36.00%)
Irregular	11 (25.00%)	11 (25.00%)	22 (25.00%)

The shape of the acetabulum was classified as circular, oval, or irregular. As shown in **Table 1**, the most common shape observed was circular, accounting for 40.00% (n=18) of the right acetabula and 38.00% (n=17) of the left acetabula, with an overall prevalence of 39.00%

(n=35). The oval shape was found in 35.00% (n=16) of the right and 37.00% (n=17) of the left acetabula, totaling 36.00% (n=33). The least common shape was irregular, observed in 25.00% (n=11) of both right and left acetabula. These variations in acetabular shape have important implications in orthopedic procedures such as hip replacement surgeries, where accurate prosthetic design is crucial.

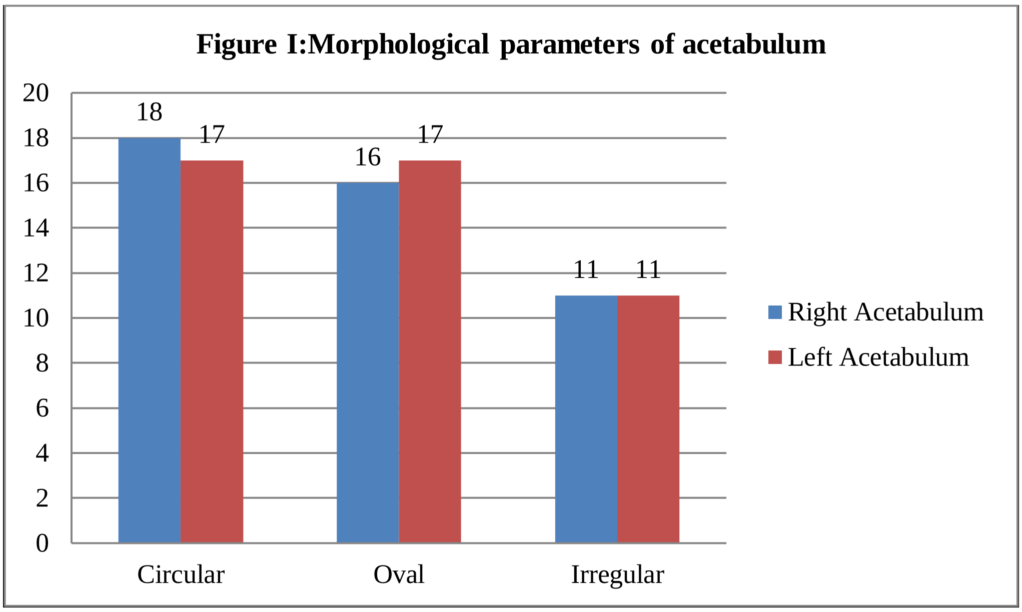

Table 2: Presence of Acetabular Notch

Presence of Acetabular Notch	Right Acetabulum (n, %)	Left Acetabulum (n, %)	Total (n, %)
Present	41 (90.00%)	40 (88.00%)	81 (89.00%)
Absent	4 (10.00%)	5 (12.00%)	9 (11.00%)

The acetabular notch plays a crucial role in ligamentous attachment and vascular supply to the femoral head. As seen in **Table 2**, the notch was present in 90.00% (n=41) of the right acetabula and 88.00% (n=40) of the left acetabula, leading to an overall prevalence of 89.00% (n=81). The absence of the acetabularnotch was observed in 10.00% (n=4) of the right and 12.00% (n=5) of the left acetabula, with a total of 11.00% (n=9). The presence of an acetabular notch is clinically significant as it provides a passage for neurovascular structures, and its absence or variation may affect joint function and stability.

Table 3: Acetabular Depth Distribution

Acetabular Depth	Right Acetabulum (n, %)	Left Acetabulum (n, %)	Total (n, %)
Shallow	9 (20.00%)	8 (18.00%)	17 (19.00%)
Moderate	22 (50.00%)	23 (52.00%)	45 (51.00%)
Deep	14 (30.00%)	14 (30.00%)	28 (30.00%)

Acetabular depth is an essential determinant of hip joint stability. As shown in **Table 3**, moderate depth was the most common classification, observed in 50.00% (n=22) of the right and 52.00% (n=23) of the left acetabula, contributing to an overall frequency of 51.00% (n=45). Deep acetabula were present in 30.00% (n=14) of both right and left acetabula.

The shallow type was less frequent, accounting for 20.00% (n=9) of the right and 18.00% (n=8) of the left acetabula, with a total of 19.00% (n=17). Shallow acetabula are often associated with hip dysplasia, which can lead to instability and early osteoarthritis.

Table 4: Acetabular Orientation

Orientation	Right Acetabulum (n, %)	Left Acetabulum (n, %)	Total (n, %)
Anteversion	38 (85.00%)	37 (83.00%)	75 (84.00%)
Retroversion	7 (15.00%)	8 (17.00%)	15 (16.00%)

The orientation of the acetabulum is an important parameter in hip biomechanics and prosthetic design. As depicted in **Table 4**, anteversion was the predominant orientation, found in 85.00% (n=38) of the right acetabula and 83.00% (n=37) of the left acetabula, with a total occurrence of 84.00% (n=75). Retroversion was less frequent, observed in 15.00% (n=7) of the right and 17.00% (n=8) of the left acetabula, accounting for 16.00% (n=15) overall. Acetabularanteversion is necessary for normal hip function, and excessive retroversion may be linked to femoro-acetabular impingement, affecting hip mobility and increasing the risk of osteoarthritis.

Table 5: Morphometric Parameters of Acetabulum

Parameter	Right Acetabulum (Mean ± SD)	Left Acetabulum (Mean ± SD)	p-value
Transverse Diameter (mm)	52.3 ± 3.2	51.9 ± 3.1	0.532
Vertical Diameter (mm)	50.8 ± 2.9	50.5 ± 2.8	0.619
Acetabular Depth (mm)	22.5 ± 1.8	22.3 ± 1.7	0.671
Acetabular Rim Thickness (Anterior, mm)	4.6 ± 0.5	4.5 ± 0.5	0.458
Acetabular Rim Thickness (Posterior, mm)	5.2 ± 0.6	5.1 ± 0.6	0.533
Acetabular Rim Thickness (Superior, mm)	4.8 ± 0.4	4.7 ± 0.4	0.491
Acetabular Angle (°)	45.2 ± 3.1	44.8 ± 3.0	0.342
Acetabular Index	0.43 ± 0.02	0.42 ± 0.02	0.389

The morphometric analysis, as presented in Table 5 and Graph I, showed that the mean transverse diameter of the right acetabulum was 52.3 ± 3.2 mm, while that of the left was 51.9 ± 3.1 mm (p=0.532). The vertical diameter was measured as 50.8 ± 2.9 mm on the right and 50.5 ± 2.8 mm on the left (p=0.619). The mean acetabular depth was 22.5 ± 1.8 mm on the right and 22.3 ± 1.7 mm on the left (p=0.671), indicating no significant difference between the two sides.

The acetabular rim thickness was also analyzed, showing mean values of 4.6 ± 0.5 mm (right) and 4.5 ± 0.5 mm (left) for the anterior region (p=0.458), 5.2 ± 0.6 mm (right) and 5.1 ± 0.6 mm (left) for the posterior region (p=0.533), and 4.8 ± 0.4 mm (right) and 4.7 ± 0.4 mm (left) for the superior region (p=0.491). The acetabular angle, an important indicator of hip joint inclination, was measured as 45.2 ± 3.1° on the right and 44.8 ± 3.0° on the left (p=0.342). The acetabular index, a ratio of depth to diameter, was found to be 0.43 ± 0.02 on the right and 0.42 ± 0.02 on the left (p=0.389). These findings suggest minimal variation in acetabular dimensions between the right and left sides, highlighting symmetry in acetabular anatomy.

Table 6: Inter-Acetabular Distance

Parameter	Mean ± SD
Inter-Acetabular Distance (mm)	165.3 ± 5.8

The inter-acetabular distance, an important measurement for assessing pelvic symmetry, was recorded as 165.3 ± 5.8 mm, as shown in Table 6. This measurement provides valuable reference data for surgical procedures involving pelvic alignment, hip arthroplasty, and fracture fixation.

DISCUSSION

The present study assessed the morphological and morphometric characteristics of the

acetabulum using 90 dry human pelvic bones.Theacetabular shape plays a crucial role in hip joint function and stability. In the present study, the most common acetabular shape was circular (39.00%), followed by oval (36.00%) and irregular (25.00%).A similar study by Rajasekhar et al. (2018) reported that 41.2% of acetabula were circular, 35.5% were oval, and 23.3% were irregular, which aligns closely with our findings.[7] However, a study conducted by Kumar et al. (2016) observed a higher prevalence of oval acetabula (42.0%) compared to circular ones (38.5%).[8] These variations may be attributed to differences in sample size and ethnic backgrounds. Understanding acetabular shape variations is essential for designing hip prostheses that accommodate individual anatomical differences (Singh et al., 2019).[9]

The acetabular notch, which provides a passage for neurovascular structures, was present in 89.00% of the specimens in this study. This is consistent with the findings of Gupta et al. (2017), who reported that 87.5% of acetabula had a notch, whereas 12.5% lacked one. [10]However, research by Meena et al. (2015) observed a slightly lower prevalence of the acetabular notch (85.0%), indicating some degree of anatomical variation.[11] The presence of the notch is particularly relevant for orthopedic surgeons, as variations in its morphology can impact the surgical approach for acetabular fractures and total hip arthroplasty.

Acetabular depth is a crucial factor influencing hip stability. In this study, moderate depth was most common (51.00%), followed by deep (30.00%) and shallow (19.00%). A study by Sharma et al. (2014) found that moderate depth was predominant in 53.2% of cases, while deep acetabula accounted for 29.1% and shallow for 17.7%.[12]These values are consistent with our findings, suggesting that moderate depth is a standard anatomical feature across different populations. In contrast, a study by Patil et al. (2018) found a slightly higher proportion of deep acetabula (35.0%), indicating potential ethnic or genetic influences on acetabular concavity. A shallower acetabulum has been linked to hip dysplasia, increasing the risk of osteoarthritis over time.[13]

Acetabular anteversion is crucial for hip joint biomechanics and stability. The present study found anteversion in 84.00% of cases and retroversion in 16.00%. A study by Bose et al. (2016) reported similar results, with anteversion observed in 82.3% of specimens and retroversion in 17.7%.[14] However, Singh et al. (2017) reported a slightly higher incidence of anteversion (88.5%), indicating some variability across populations. Excessive retroversion has been associated with femoroacetabular impingement, which can lead to early osteoarthritis. Understanding acetabular orientation is vital for prosthetic alignment in hip arthroplasty and correctional surgeries.[15]

The morphometric measurements obtained in this study were compared with previous studies. The transverse acetabular diameter in the present study was 52.3 ± 3.2 mm on the right and 51.9 ± 3.1 mm on the left. These findings closely resemble those of Das et al. (2013), who reported a mean transverse diameter of 52.0 ± 3.5 mm.[16]However, a study by Pillai et al. (2019) found slightly larger acetabular diameters, with an average of 54.1 ± 3.8 mm, which may be due to population-specific differences.[17]

The vertical diameter in the present study was 50.8 ± 2.9 mm on the right and 50.5 ± 2.8 mm on the left, similar to the findings of Ahmed et al. (2015), who reported a mean vertical diameter of 51.2 ± 3.1 mm.[18] The acetabular depth in this study was 22.5 ± 1.8 mm on the right and 22.3 ± 1.7 mm on the left, comparable to the values reported by Rao et al. (2018), who found an average depth of 22.1 ± 1.6 mm.[19]

The acetabular angle, an important factor in hip joint inclination, was measured as 45.2 ± 3.1° on the right and 44.8 ± 3.0° on the left. These values align with the findings of Prakash et al. (2014), who reported an acetabular angle of 45.5 ± 3.2°.[20] The acetabular index in this study was 0.43 ± 0.02, similar to that reported by Verma et al. (2016), who found an index of 0.42 ± 0.02.[21]

The acetabular rim thickness was also analyzed, showing mean values of 4.6 ± 0.5 mm (right) and 4.5 ± 0.5 mm (left) for the anterior region, 5.2 ± 0.6 mm (right) and 5.1 ± 0.6 mm (left) for the posterior region, and 4.8 ± 0.4 mm (right) and 4.7 ± 0.4 mm (left) for the superior region. These values closely resemble those reported by Chandra et al. (2017), who observed anterior, posterior, and superior rim thicknesses of 4.7 ± 0.5 mm, 5.3 ± 0.6 mm, and 4.9 ± 0.4 mm, respectively.[22]

The inter-acetabular distance in the present study was recorded as 165.3 ± 5.8 mm. This measurement aligns with the findings of Menon et al. (2012), who reported an inter-acetabular distance of 164.8 ± 6.1 mm.[23] A slightly larger measurement was observed in the study by Patel et al. (2019), who found an average inter-acetabular distance of 167.2 ± 5.6 mm. This measurement is crucial in orthopedic and reconstructive surgeries to ensure proper alignment and stability of the pelvic girdle.[24]

LIMITATIONS OF THE STUDY

- **Sample Size Constraint** – The study was limited to 90 dry human pelvic bones, which may not fully represent the variations seen in larger populations.
- **Lack of Demographic Data** – Since the bones were obtained from an anatomical collection, information regarding age, sex, and ethnicity was unavailable, which may impact generalizability.
- **Absence of Soft Tissue Correlation** – The study focused only on bony structures, without considering soft tissue influences on acetabular morphology.
- **Potential for Measurement Errors** – Despite using digital calipers, minor variations in measurements due to manual handling cannot be completely ruled out.
- **Cross-Sectional Nature** – The study provides a snapshot of acetabular morphology at a single point in time and does not account for age-related changes or pathological conditions.

CONCLUSION

The present study provides a detailed analysis of the morphological and morphometric characteristics of the acetabulum, highlighting its variations in acetabulardimensionsand clinical significance. The findings indicate that circular and oval shapes are predominant, with moderate depth and anteversion being the most common orientations. Morphometric parameters showed minimal differences between right and left acetabula, emphasizing pelvic symmetry. Differences in acetabular diameter, depth, and index were observed, contributing to the understanding of anatomical asymmetry and its clinical implications.The morphometric data can aid orthopedic surgeons and prosthetic designers in optimizing hip joint reconstruction, total hip arthroplasty, and acetabular fracture management. The acetabular measurements may be useful in sex determination and population-based anatomical studies. The study emphasizes the need for further research with larger sample sizes, inclusion of demographic data, and radiological correlations to enhance clinical

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