

Morphometric Evaluation of the Acetabulum in Human Hip Bones for Prosthesis Design

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Abstract:

Background: The acetabulum is a major component of the hip joint and exhibits considerable variation in size, shape and depth among different populations. Accurate knowledge of acetabular morphometry is essential for understanding hip biomechanics and for developing appropriately sized acetabular components for total hip arthroplasty. Population-specific anatomical data are particularly important because commercially available implants may not adequately represent the morphology of all populations.

Aim: To evaluate the morphometric characteristics of the acetabulum in human hip bones and assess their implications for prosthesis design.

Materials and Methods: This retrospective observational study was conducted in the Department of Anatomy, RDJMMC, Turki, Muzaffarpur, Bihar, over a period of one and a half years. A total of 64 adult human hip bones were evaluated. Acetabular parameters including transverse diameter, vertical diameter, acetabular depth, acetabular notch width, acetabular circumference and estimated acetabular capacity were measured using standard osteometric techniques. Morphological characteristics of the acetabulum were also recorded. Continuous variables were expressed as mean $\pm$ standard deviation. Differences between right and left sides were evaluated using the independent Student's *t*-test, while categorical variables were compared using the chi-square test. A *p* value <0.05 was considered statistically significant.

Results: The mean transverse diameter of the acetabulum was approximately 47.9 ± 3.8 mm, while the mean vertical diameter was 50.1 ± 4.1 mm. Mean acetabular depth was 24.0 ± 2.2 mm and mean notch width was 23.1 ± 4.1 mm. No statistically significant difference was observed between right and left sides for transverse diameter, vertical diameter or acetabular depth ($p>0.05$). A significant difference was observed for acetabular notch width ($p=0.041$). The most common acetabular morphology was the rounded/oval type, followed by horseshoe and irregular forms.

Conclusion: The study demonstrates measurable variation in acetabular dimensions and morphology. These findings emphasize the importance of population-specific morphometric data in the design and selection of acetabular components. Such anatomical information may assist orthopaedic surgeons, anatomists and biomedical engineers in developing implants with improved anatomical conformity and stability.

Keywords: Acetabulum; Hip Bone; Morphometry; Acetabular Depth; Hip Prosthesis; Total Hip Arthroplasty; Osteology; Implant Design.

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Introduction

The socket component of the hip joint is formed by the acetabulum, a cup-shaped hollow on the lateral aspect of the hip bone. The ilium, ischium, and pubis fuse together to produce this extremely secure ball-and-socket synovial joint, which articulates with the femoral head. The acetabular notch is situated inferiorly, and the acetabulum is made up of an articular lunate surface encircling the non-articular acetabular fossa. Its anatomical design preserves joint stability while facilitating effective load transfer from the femur to the pelvis. Because even

slight variations in acetabular geometry can affect hip biomechanics, the acetabulum's size and orientation are clinically significant. During total hip arthroplasty (THA), acetabular reconstruction, and implant placement, factors such as acetabular diameter, depth, inclination, version, and coverage are crucial. Because improper acetabular orientation can lead to instability, impingement, excessive wear, and early implant failure, modern THA places an increasing emphasis on customized component location [1].

Acetabular shape varies significantly between individuals and between populations. In comparison to Western and other Asian groups, a CT-based research of the Northern Indian population revealed variations in acetabular depth and other characteristics, with females exhibiting comparatively shallower acetabula than males. Similar variations in acetabular dimension, depth, notch width, and other morphometric parameters have been shown in recent osteological investigations from India. Understanding these dimensions is very important when designing prostheses. Acetabular implants must replicate the anatomical center of rotation while providing sufficient coverage and reliable fixation. Inadequate fixation, excessive bone loss, or changed hip biomechanics might arise from a mismatch between implant geometry and native acetabular morphology. The possibility for utilizing population-specific morphometric data in customized implant fabrication has expanded due to recent advancements in three-dimensional imaging, patient-specific planning, and additive manufacturing [2, 3].

Even though acetabular morphology in various Indian communities has been assessed in a number of studies, regional variation is still not well understood. Therefore, data from Bihar and surrounding areas may offer helpful reference values for anthropological research, orthopedic implant development, and anatomical teaching. In order to assess the morphometric features of the acetabulum in 64 human hip bones and ascertain the significance of these data for prosthesis design, the current study was conducted [4].

Materials and Methods

Study Design and Setting: A retrospective observational osteological study was conducted in the Department of Anatomy, RDJMMC, Turki, Muzaffarpur, Bihar, over a period of one and a half years.

Study Sample: A total of 64 adult human hip bones available in the osteology collection of the Department of Anatomy were retrospectively evaluated.

Inclusion Criteria

1. Adult human hip bones.
2. Bones with identifiable acetabular margins and landmarks.
3. Specimens with sufficiently preserved acetabular morphology.

4. Bones suitable for accurate osteometric measurements.

Exclusion Criteria

1. Bones showing gross deformity.
2. Fractured or damaged acetabular margins.
3. Specimens with pathological changes.
4. Incomplete hip bones that prevented reliable measurement.

Morphometric Parameters: The following parameters were evaluated:

1. **Transverse diameter of acetabulum:** Maximum transverse distance across the acetabular opening.
2. **Vertical diameter:** Maximum superoinferior diameter of the acetabulum.
3. **Acetabular depth:** Maximum perpendicular depth from the deepest point of the acetabular cavity to the plane of its rim.
4. **Acetabular notch width:** Maximum distance across the acetabular notch.
5. **Acetabular circumference:** Circumference measured along the acetabular rim.
6. **Acetabular capacity:** Estimated volume/capacity of the acetabular cavity where measurement was feasible.
7. **Acetabular shape:** Morphology was classified according to the overall configuration of the acetabular rim/cavity.

Measurements were obtained using a calibrated digital vernier caliper and appropriate osteometric instruments. Measurements were recorded in millimetres, while capacity was expressed in millilitres.

Statistical Analysis: Data were entered into a spreadsheet and analyzed using statistical software. Continuous variables were expressed as mean $\pm$ standard deviation (SD). Right- and left-sided measurements were compared using the independent Student's t-test. Categorical morphological variables were analyzed using the chi-square test. A p value <0.05 was considered statistically significant.

Results

A total of 64 adult human hip bones were evaluated. For analysis of laterality, the specimens were considered according to the side of the hip bone. The overall morphometric measurements demonstrated moderate variability between specimens.

Table 1: Distribution of study specimens according to side

Side	Number	Percentage
Right	32	50.0
Left	32	50.0
Total	64	100.0

Table 2: Morphometric measurements of the acetabulum according to side

Parameter	Right (n=32), Mean $\pm$ SD	Left (n=32), Mean $\pm$ SD	p value
Transverse diameter (mm)	48.2 $\pm$ 3.7	47.6 $\pm$ 3.9	0.524
Vertical diameter (mm)	50.4 $\pm$ 4.0	49.8 $\pm$ 4.2	0.566
Acetabular depth (mm)	24.2 $\pm$ 2.1	23.8 $\pm$ 2.3	0.472
Notch width (mm)	24.1 $\pm$ 4.2	22.1 $\pm$ 3.9	0.041
Acetabular circumference (mm)	151.8 $\pm$ 12.1	149.5 $\pm$ 11.7	0.452
Acetabular capacity (mL)	27.4 $\pm$ 4.9	26.7 $\pm$ 5.1	0.585

The mean transverse diameter was 48.2 $\pm$ 3.7 mm on the right and 47.6 $\pm$ 3.9 mm on the left. The difference was not statistically significant (p=0.524). Similarly, no significant side-related difference was observed for vertical diameter

(p=0.566), acetabular depth (p=0.472), circumference (p=0.452) or capacity (p=0.585).

However, the mean acetabular notch width was greater on the right side than on the left side, and this difference was statistically significant (p=0.041).

Table 3: Overall morphometric characteristics of the acetabulum

Parameter	Mean $\pm$ SD	Minimum	Maximum
Transverse diameter (mm)	47.9 $\pm$ 3.8	40.8	55.7
Vertical diameter (mm)	50.1 $\pm$ 4.1	42.3	58.6
Acetabular depth (mm)	24.0 $\pm$ 2.2	19.4	28.9
Notch width (mm)	23.1 $\pm$ 4.1	15.6	31.8
Acetabular circumference (mm)	150.7 $\pm$ 11.9	128.5	174.2
Acetabular capacity (mL)	27.1 $\pm$ 5.0	17.8	38.9

The overall mean transverse and vertical diameters were 47.9 $\pm$ 3.8 mm and 50.1 $\pm$ 4.1 mm, respectively. The mean depth was 24.0 $\pm$ 2.2 mm.

Table 4: Distribution of acetabular morphology

Acetabular morphology	Number	Percentage
Rounded/oval	30	46.9
Horseshoe	21	32.8
Irregular	8	12.5
Angular	5	7.8
Total	64	100.0

The rounded/oval morphology was the most frequently observed configuration (46.9%), followed by the horseshoe type (32.8%). Irregular and angular forms accounted for 12.5% and 7.8%,

respectively. The observed distribution demonstrated significant morphological heterogeneity (p=0.018).

Table 5: Association between side and predominant acetabular morphology

Morphology	Right n (%)	Left n (%)	p value
Rounded/oval	15 (46.9)	15 (46.9)	0.962
Horseshoe	10 (31.3)	11 (34.4)	
Irregular	4 (12.5)	4 (12.5)	
Angular	3 (9.4)	2 (6.3)	

No statistically significant association was observed between side and acetabular morphology (p=0.962).

Discussion

The current study assessed the acetabulum's morphometric properties in 64 human hip bones and found quantifiable differences in acetabular

morphology and size. The average acetabular depth was 24.0 mm, the vertical diameter was 50.1 mm, and the transverse diameter was roughly 47.9 mm. Although variations amongst groups are anticipated because to the significant geographic and individual heterogeneity in acetabular shape, these results are generally similar with previously published Indian

osteological research. Because its dimensions dictate the size, position, and coverage of the acetabular component during total hip arthroscopy, the acetabulum is particularly significant in reconstructive orthopedics. Surgeons and implant designers can choose an appropriately sized component and reduce needless acetabular bone removal by having a thorough understanding of the native acetabular shape. Restoring normal hip biomechanics also requires accurate restoration of the center of rotation and sufficient component coverage [5, 6].

Although the transverse dimension was somewhat larger on the right than the left in the current analysis, the difference was not statistically significant. Similarly, there were no appreciable side-to-side variations in acetabular depth or vertical diameter. This implies that the primary acetabular dimensions may show a rather balanced distribution between sides notwithstanding individual anatomical heterogeneity. Similar results have been documented in osteological studies conducted in India, where the majority of linear parameters did not show statistically significant bilateral differences. Transverse diameters of about 49 mm and acetabular depths of about 23 mm were reported in a recent South Indian research; these values are roughly similar to the current findings. The notable variation in acetabular notch width suggests that there may be more bilateral diversity in some localized anatomical features than in the major dimensions. Because it serves as a crucial landmark for acetabular orientation and reconstruction, the acetabular notch is significant both physically and surgically [7, 8].

In order to ensure proper component orientation, modern THA procedures include an increasing emphasis on anatomical landmarks and customized positioning. The current study's prevalence of rounded/oval acetabular morphology highlights the need of taking shape into account in addition to linear measurements. The three-dimensional geometry of the native acetabulum may not be sufficiently replicated by implant selection based only on diameter. Similarly, CT-based studies have demonstrated that acetabular morphology varies by population and that acetabular depth, version, and coverage can differ significantly between people. The significance of demographic and sex-related structural variation was highlighted in a Northern Indian CT research where females showed a considerably lower acetabular depth ratio and larger extrusion index than males. As patient-specific and three-dimensional implant technologies have advanced, the significance of these findings has grown [9, 10].

Customized acetabular components can be created based on anatomical features unique to each patient thanks to three-dimensional printing. It is possible to

adapt implant architecture to complex acetabular anatomy and bone abnormalities, according to studies using customized 3D-printed acetabular cups. Additionally, recent studies have emphasized the significance of customized design and computational modeling in acetabular reconstruction. While patient-specific methods may lessen the drawbacks of uniform implant shape, three-dimensional modeling can help with implant selection, placement, and postoperative mechanical behavior prediction. Therefore, the development of acetabular prostheses appropriate for the Indian population may benefit from the current findings. The morphometric databases from populations with varying skeletal measurements may serve as part of the foundation for current implants [11].

Improved implant sizing and design can be facilitated by regional anatomical information, especially in situations where lower acetabular dimensions or unique geometric patterns are present. The study has some limitations. The sample size was relatively small, and the retrospective osteological design limited the availability of demographic information such as age, sex and body stature. Furthermore, dry-bone measurements cannot completely reproduce the three-dimensional morphology obtained by CT-based assessment in living individuals. Larger multicentric studies incorporating CT-derived three-dimensional measurements, sex-specific analysis and biomechanical modelling would provide stronger evidence for population-specific implant development [12].

Conclusion

There is significant anatomical heterogeneity in acetabular size and morphology, according to the current morphometric analysis of 64 human hip bones. For comprehending the hip's bony anatomy, the mean acetabular transverse diameter, vertical diameter, and depth offer helpful reference data. Acetabular notch width showed considerable side-related variation, while most important linear metrics did not reveal significant bilateral differences. The findings emphasize that acetabular prosthesis design should consider not only implant diameter but also acetabular depth, notch configuration, circumference and overall three-dimensional morphology. Population-specific morphometric databases can help improve implant sizing and anatomical conformity during total hip arthroplasty.

The increasing application of CT-based three-dimensional reconstruction, computational modelling and additive manufacturing provides opportunities to translate such anatomical data into patient-specific or population-optimized acetabular implants. Further studies with larger samples, documented sex distribution and advanced three-

dimensional imaging are recommended to establish comprehensive regional reference standards for the Indian population.

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