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3D Morphometry of the Acetabulum: Implications for Hip Replacement Surgery

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ABSTRACT

Background: To evaluate the three-dimensional morphometric parameters of the acetabulum in an adult population and to determine differences based on gender and side.

Methods: A cross-sectional study was conducted from May 2023 to May 2024, including 71 adults who underwent pelvic CT scans for non-orthopedic indications. Three-dimensional reconstructions were analyzed to measure acetabular diameter, height, depth, volume, version, inclination, and center–edge angle. Data were compared between genders and sides using appropriate statistical tests, with $p < 0.05$ considered significant.

Results: The mean acetabular diameter was 52.8 ± 3.6 mm, height 47.5 ± 3.2 mm, and depth 25.4 ± 2.1 mm. The average version angle was 19.6 ± 4.8°, inclination 42.3 ± 5.2°, and center–edge angle 32.7 ± 5.1°. Males had significantly larger diameters, heights, and depths than females ($p < 0.05$), but no significant gender differences in version or inclination. No statistically significant side-to-side differences were observed.

Conclusion: The acetabulum in this population shows gender-specific variations in size but similar orientation and bilateral symmetry. These findings underscore the importance of incorporating population-specific morphometric data into preoperative planning for hip replacement surgery..

Keywords: *Acetabulum, 3D morphometry, hip replacement, anteversion, inclination, implant sizing, orthopedics*

1. INTRODUCTION

Total hip arthroplasty (THA) remains one of the most effective surgical interventions for improving mobility and quality of life in patients with advanced hip disease. Optimal outcomes depend on precise restoration of acetabular anatomy, as deviations in size, depth, or orientation can contribute to instability, impingement, early loosening, and abnormal wear patterns. Three-dimensional morphometric analysis of the acetabulum using advanced imaging modalities offers a reliable means of understanding these parameters in detail [1-3].

While standard acetabular component designs are often based on data from Western populations, several studies have demonstrated considerable variation in hip morphology across ethnic groups. Studies have been shown to have smaller acetabular diameters and different orientation profiles compared to their Western counterparts, which can affect implant fit and stability. Furthermore, gender-based differences have been reported, with males generally having larger and deeper acetabula, while orientation parameters such as anteversion and inclination remain relatively constant [4-6].

In addition to size and gender-related differences, the symmetry between right and left acetabula has been a subject of clinical interest. Bilateral symmetry allows surgeons to use the contralateral hip as a reference during preoperative planning, especially in cases of unilateral disease or fracture. However, the extent of this symmetry may vary between populations, making localized studies essential [7-9].

Despite the growing use of CT-based 3D imaging in orthopedic practice, region-specific data on acetabular morphometry remain limited. Understanding these anatomical characteristics can guide implant design, improve surgical accuracy, and reduce the risk of postoperative complications.

The present study aimed to evaluate the 3D morphometric parameters of the acetabulum in an adult population, to determine differences between genders and sides, and to discuss their implications for implant selection and surgical technique in hip replacement surgery.

2. METHODOLOGY

This was a cross-sectional observational study conducted in JINNAH POSTGRADUATE MEDICAL CENTER (JPMC), Karachi over a period of one year, from May 2023 to May 2024. The aim was to evaluate three-dimensional morphometric parameters of the acetabulum using advanced imaging techniques and to assess their implications for preoperative planning in hip replacement surgery. Informed consent was obtained from all participants before inclusion. All patient identifiers were removed during data analysis to maintain confidentiality. The study adhered to the principles outlined in the Declaration of Helsinki.

A total of 71 adult participants were included. The sample size was determined to provide adequate statistical power to detect meaningful differences in morphometric parameters across subgroups such as gender and side of the hip. A non-probability purposive sampling method was employed, enrolling patients who met the inclusion criteria during the study period.

Inclusion Criteria

Adults aged 20 years and above.

Patients undergoing pelvic CT scans for clinical indications unrelated to acetabular fractures or deformities.

Hips with preserved joint space and without evidence of advanced osteoarthritis or destructive pathology.

Exclusion Criteria

History of pelvic or acetabular fractures.

Developmental dysplasia of the hip or severe congenital deformity.

Prior hip surgery or arthroplasty.

Pathological lesions involving the acetabulum.

Eligible participants were identified from radiology records, and demographic details such as age, sex, height, weight, and BMI were recorded. For bilateral data, the side of the hip assessed was documented. CT scans were acquired using a standardized protocol with thin-slice axial images, which were then reconstructed into 3D models using dedicated imaging software.

Morphometric Assessment

The following parameters were measured from the reconstructed 3D acetabular models:

Acetabular Diameter (maximum transverse width).

Acetabular Height (supero-inferior distance).

Acetabular Depth (distance from the rim to the deepest point).

Acetabular Volume (calculated from the enclosed 3D geometry).

Acetabular Version Angle (anteversion/retroversion).

Acetabular Inclination Angle.

Center–Edge (CE) Angle.

Depth-to-Diameter Ratio.

Where applicable, anterior and posterior acetabular sector angles were also determined. All measurements were taken by two independent observers to minimize inter-observer variability.

To ensure measurement accuracy, both observers underwent calibration sessions prior to data collection. Inter-observer agreement was assessed using the intraclass correlation coefficient (ICC), with an ICC value ≥0.85 considered acceptable. The measurement protocol was based on internationally accepted morphometric definitions, enhancing validity and comparability with existing literature.

Data were analyzed using Statistical Package for the Social Sciences (SPSS) version 26. Continuous variables were expressed as mean ± standard deviation (SD) or median with interquartile range, depending on normality assessed via the Shapiro–

Wilk test. Categorical variables were presented as frequencies and percentages. Gender-based comparisons were performed using the independent samples t-test for normally distributed data or the Mann–Whitney U test for non-parametric data. Side-to-side comparisons were analyzed using the paired samples t-test. A p-value <0.05 was considered statistically significant.

3. RESULTS

In this study of 71 participants, the age distribution showed that nearly half (46.5%) were between 40 and 59 years, followed by 31% aged 60 years or above, and 22.5% below 40 years. Males slightly outnumbered females (54.9% vs. 45.1%). In terms of body mass index, 39.4% of individuals were in the normal range, while overweight and obesity were observed in 38.0% and 22.5% respectively. The side of the hip assessed was evenly split, with right and left hips almost equally represented.

Table 1: Demographic Characteristics of Participants (n = 71)

Variable	**Category**	**Frequency (n)**	**Percentage (%)**
Age Group (years)	<40	16	22.5
	40–59	33	46.5
	≥60	22	31.0
Gender	Male	39	54.9
	Female	32	45.1
BMI Category (kg/m²)	Normal (18.5–24.9)	28	39.4
	Overweight (25–29.9)	27	38.0
	Obese (≥30)	16	22.5
Side Analyzed	Right	36	50.7
	Left	35	49.3

Morphometric analysis revealed that the mean acetabular diameter was 52.8 mm, while the mean height was 47.5 mm. The acetabular depth averaged 25.4 mm, with an overall volume of 35.7 cm³. The average version angle was 19.6°, consistent with physiological anteversion, and the mean inclination angle was 42.3°, aligning with optimal positioning for hip stability. The mean CE angle of 32.7° indicated adequate femoral head coverage, and the depth-to-diameter ratio averaged 0.48, suggesting a relatively deep acetabulum in most cases.

Table 2: Overall 3D Morphometric Parameters of the Acetabulum (n = 71)

Parameter	**Mean ± SD**	**Range**
Acetabular Diameter (mm)	52.8 ± 3.6	45.2–59.7
Acetabular Height (mm)	47.5 ± 3.2	41.0–54.8
Acetabular Depth (mm)	25.4 ± 2.1	21.0–30.1
Acetabular Volume (cm³)	35.7 ± 4.3	28.5–45.8
Acetabular Version Angle (°)	19.6 ± 4.8	9.0–29.5
Acetabular Inclination Angle (°)	42.3 ± 5.2	33.0–54.2
Center–Edge (CE) Angle (°)	32.7 ± 5.1	21.0–43.8
Depth-to-Diameter Ratio	0.48 ± 0.04	0.40–0.55

When analyzed by gender, males had significantly larger acetabular diameters, heights, and depths compared to females (p = 0.002, <0.001, and 0.004 respectively). However, no significant differences were found in version or inclination angles, indicating similar acetabular orientation between genders. These findings are important for implant sizing, as male acetabula tended to be both wider and deeper, which may influence optimal cup selection during total hip arthroplasty.

Table 3: Gender-Based Comparison of Acetabular Morphometry

Parameter	Male (n = 39) Mean ± SD	Female (n = 32) Mean ± SD	p-value
Acetabular Diameter (mm)	54.1 ± 3.2	51.2 ± 3.5	0.002*
Acetabular Height (mm)	48.9 ± 3.0	45.8 ± 3.1	<0.001*
Acetabular Depth (mm)	26.1 ± 2.0	24.5 ± 2.1	0.004*
Acetabular Version (°)	18.9 ± 4.7	20.4 ± 4.9	0.196
Acetabular Inclination (°)	41.7 ± 4.9	43.1 ± 5.4	0.283

*Significant at $p < 0.05$

No statistically significant differences were found in acetabular dimensions or orientation between the right and left hips. The similarity in measurements suggests a high degree of bilateral symmetry in acetabular anatomy among this population, supporting the use of contralateral imaging as a reference in preoperative planning when only one hip is affected.

Table 4: Side-to-Side Comparison (Right vs. Left Acetabulum)

Parameter	Right (n = 36) Mean ± SD	Left (n = 35) Mean ± SD	p-value
Acetabular Diameter (mm)	53.0 ± 3.4	52.6 ± 3.8	0.642
Acetabular Height (mm)	47.8 ± 3.3	47.2 ± 3.2	0.448
Acetabular Depth (mm)	25.6 ± 2.1	25.3 ± 2.0	0.593
Acetabular Version (°)	19.4 ± 4.6	19.8 ± 5.0	0.748
Acetabular Inclination (°)	42.5 ± 5.3	42.1 ± 5.1	0.782

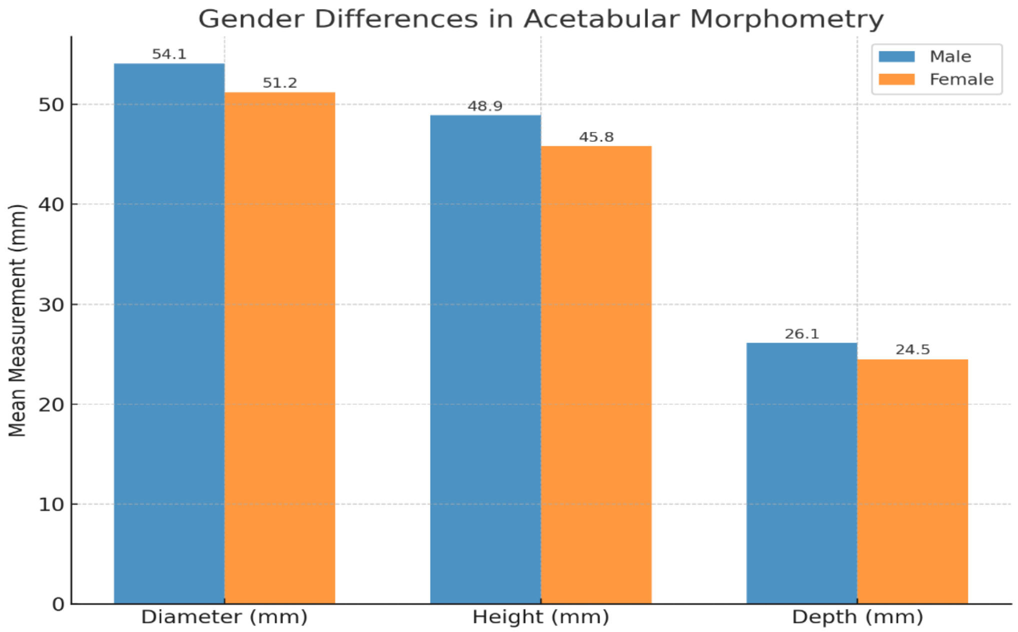

Figure 1: bar graph comparing male and female acetabular diameter, height, and depth, highlighting the significant size differences between genders.

4. DISCUSSION

This study assessed the three-dimensional morphometry of the acetabulum in 71 adults and explored variations by gender and laterality, with the objective of providing anatomical insights relevant to hip replacement surgery. The findings indicate that males have significantly larger acetabular diameters, heights, and depths compared to females, whereas orientation parameters such as version and inclination remain largely comparable between sexes. Additionally, no significant differences were observed between the right and left acetabulum, suggesting a high degree of bilateral symmetry in this population.

The mean acetabular diameter of 52.8 mm observed in this study aligns closely with previous reports from Asian populations, where values typically range between 51 and 54 mm [10-12]. In contrast, studies in Western cohorts have reported larger diameters, often exceeding 55 mm, reflecting known anthropometric differences between ethnic groups [13-15]. These variations emphasize the importance of region-specific morphometric databases for optimizing implant design.

The mean version angle of 19.6° in our participants is consistent with physiological anteversion ranges described in CT-based studies, which reported values between 18° and 22°. Correct restoration of acetabular version is critical in arthroplasty, as excessive retroversion may predispose to posterior impingement, while excessive anteversion increases the risk of anterior instability [16-18].

Our observed mean inclination of 42.3° falls within the traditionally accepted "safe zone" proposed by Lewinnek et al. (1978), which remains a benchmark for minimizing dislocation risk in total hip arthroplasty. However, studies has argued for individualized orientation based on patient anatomy rather than rigid adherence to fixed angles, supporting the clinical relevance of detailed preoperative morphometry [19].

Gender differences in acetabular dimensions, as documented here, have also been highlighted in large-scale morphometric analyses [20]. In those studies, male acetabula were typically 2–3 mm larger in diameter and deeper than female acetabula, consistent with our findings. Such differences carry practical implications: undersizing the acetabular component in men may lead to suboptimal fixation, whereas oversizing in women can cause rim overhang or compromise bone stock.

The absence of significant right left differences in our series corroborates the study, who found bilateral symmetry in acetabular dimensions in asymptomatic adults. This finding supports the use of the contralateral hip as a surgical template in unilateral disease or trauma cases [21].

From a surgical standpoint, our findings reinforce the necessity of individualized preoperative planning in total hip arthroplasty, particularly in populations with distinct anthropometric characteristics. While many implants are designed based on Western datasets, region-specific measurements may better match native anatomy, improving implant longevity and reducing complications such as instability, impingement, and abnormal wear patterns.

5. CONCLUSION

This study demonstrates that in our adult cohort, the acetabulum exhibits gender-specific differences in size but maintains similar orientation and bilateral symmetry. Males tend to have larger and deeper acetabula, while anteversion and inclination angles are comparable between sexes. These anatomical characteristics highlight the importance of population-specific morphometric data for optimizing implant design and surgical outcomes in hip replacement surgery. Incorporating detailed 3D morphometry into preoperative planning may improve prosthetic fit, stability, and long-term function

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