

Apex Angle and Lateral Facet Ratio in Dry Human Patellae: Surgical and Morphological Implications

Sheuli Akter¹, Mahmuda Khatoun², Samira Ananna³, Shaila Mahmud⁴

Abstract

Background: The patella is a key determinant of patellofemoral congruence, tracking, and contact stress. Small variations in its shape can influence patellofemoral pain, instability, and postoperative anterior knee symptoms. Among patellar morphologic indices, the apex angle reflects inferior pole geometry, while the lateral facet ratio quantifies lateral facet dominance; both parameters may affect trochlear engagement and patellar tilt. This study aimed to assess sex-related differences in apex angle, lateral facet ratio, and major patellar morphometric parameters in dry adult human left patellae, highlighting their potential surgical and morphological implications.

Materials & Methods: This cross sectional analytical study was conducted at the Department of Anatomy, Dhaka Medical College, from January 2018 to June 2019. A total of 150 dry adult human left patellae of unknown sex were examined. Sex was assigned using linear discriminant function analysis based on maximum patellar height and width, classifying 92 specimens as male and 58 as female. Morphometric measurements were recorded using a digital slide caliper, a flexible wire for curved surfaces, and a protractor for apex angle. Weight and volume were measured using an electronic balance and a graduated glass cylinder, respectively.

Results: Among the 150 dry left patellae, 92 (61.33%) were classified as male and 58 (38.67%) as female. Male patellae were significantly larger in major dimensions and mass, including height (42.10 ± 1.99 vs 36.16 ± 2.31 mm), width (42.87 ± 1.80 vs 36.94 ± 1.58 mm), thickness (20.73 ± 1.25 vs 18.69 ± 1.39 mm), weight (10.59 ± 2.13 vs 6.79 ± 1.45 g), and volume (10.88 ± 1.98 vs 7.10 ± 1.34 cm³), all $p < 0.01$. Males also exhibited greater ridge height and facet widths (all $p < 0.01$), with small but significant differences in facet thickness ($p = 0.001-0.002$). In contrast, females showed a significantly higher apex angle ($110.17 \pm 10.80^\circ$ vs $104.65 \pm 6.80^\circ$, $p < 0.01$) and a higher lateral facet ratio (0.61 ± 0.04 vs 0.58 ± 0.03 , $p < 0.01$), corresponding to mean differences of 5.52° (95% CI: 2.37-8.67; $g = 0.64$) and 0.03 (95% CI: 0.018-0.042; $g = 0.87$), respectively. Patellar index and median ridge position did not differ significantly between the sexes ($p = 0.599$ and $p = 0.127$). Correlation analysis showed a weak, non-significant association between apex angle and lateral facet ratio ($r = 0.11$, $p = 0.167$), whereas lateral facet ratio correlated moderately and negatively with facet widths ($r = -0.36$, $p < 0.01$).

Conclusion: Male patellae were significantly larger in overall size and facet dimensions. Conversely, female patellae exhibited a higher apex angle and lateral facet ratio. No sex-based differences were observed in patellar index or ridge position.

Keywords: Patella morphometry, Apex angle, Lateral facet ratio, Patellofemoral biomechanics, Sexual dimorphism

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¹Assistant Professor, Department of Anatomy, IBN Sina Medical College, Dhaka, Bangladesh

²Associate Professor, Department of Anatomy, IBN Sina Medical College, Dhaka, Bangladesh

³Assistant Professor, Department of Anatomy, IBN Sina Medical College, Dhaka, Bangladesh

⁴Assistant Professor, Department of Anatomy, Green Life Medical College, Dhaka, Bangladesh

Correspondence: Dr. Sheuli Akter, E-mail: dresheul122@gmail.com

Introduction

The patella, the body's largest sesamoid bone, plays a critical role in determining patellofemoral joint congruence, tracking, and contact stress. Even minor variations in patellar shape can significantly alter the biomechanics of the extensor mechanism and may contribute to clinical conditions such as patellofemoral pain (PFP), recurrent instability, and anterior knee pain following surgical reconstruction

or arthroplasty. Two morphologic indices are particularly important in this context: the apex angle, which reflects the geometry of the inferior pole and overall patellar contour, and the lateral facet ratio, a quantitative marker of lateral facet dominance that can influence trochlear engagement and the tendency for patellar tilt. Epidemiologically, PFP is among the most common knee complaints in adolescents and active adults. A systematic review and meta-analysis reported an annual prevalence of approximately 22.7% in the general adult population, highlighting its substantial impact on physical function and healthcare utilization.¹ Data from Asian communities indicate a similar burden; for instance, a survey of young adults in China reported a PFP prevalence of 20.7%, underscoring its regional relevance beyond Western cohorts.² International consensus and recent best-practice guidelines emphasize that PFP is multifactorial and often persistent, requiring precise biomechanical assessment to inform individualized management strategies.^{3,4} Patellar instability is another clinically significant disorder, particularly among younger individuals. A large population-based cohort study found an incidence of first-time lateral patellar dislocation of 23.2 per 100,000 person-years, with a peak incidence of 147.7 per 100,000 in adolescents aged 14 to 18 years.⁵ As both pain and instability are influenced by osseous morphology, robust reference values for patellar form—especially facet proportions and ridge-related geometry—are essential for risk assessment, surgical planning, and implant design. Furthermore, patellar morphometry is directly relevant to patellar resurfacing and component sizing in total knee arthroplasty (TKA). Inadequate restoration of thickness, facet symmetry, and tracking can increase the risk of complications and subsequent revision surgery.⁶

Imaging and morphometric studies indicate that patellar shape, facet configuration, and ridge-related parameters vary significantly by sex and ethnicity. This highlights the need for population-specific datasets rather than relying on universal reference values.^{7,8,9} While recent studies continue to document measurable sex differences in patellar dimensions and articular architecture^{8,9}, high-quality

osteometric reference data for the Bangladeshi population remain limited. Furthermore, the apex angle and lateral facet ratio are not consistently reported alongside standard linear dimensions in existing literature. This study aims to determine sex-specific differences in the apex angle, lateral facet ratio, and key morphometric dimensions of dry adult human left patellae, while exploring their potential surgical and morphological implications.

Materials & Methods

This cross-sectional analytical study was conducted in the Department of Anatomy at Dhaka Medical College (DMC), Dhaka, from January 2018 to June 2019. The study sample comprised one hundred fifty (150) dry adult human left patellae of unknown sex. Specimens were excluded if they exhibited fractures, evident deformities, or if any portion of the bone was missing or incomplete, rendering them unsuitable for accurate morphometric assessment. After collection, the sex of each specimen was determined using linear discriminant function analysis, following the methodology described by Kayalvizhi et al.¹⁰ Based on this analysis, the 150 specimens were classified into 92 male and 58 female patellae (Figure 1).

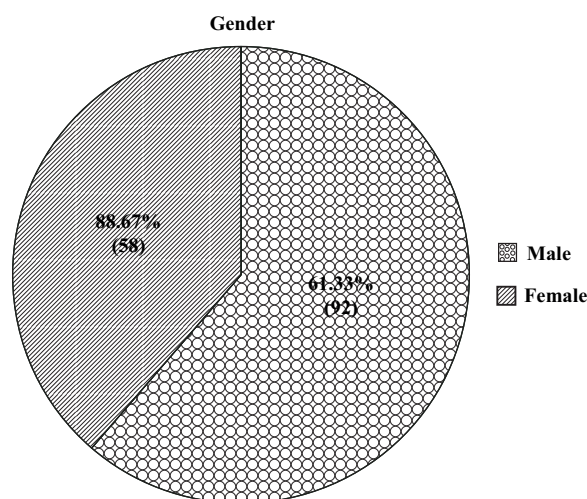


Fig.-1: Sex distribution of dry human patellae included in the study (N = 150). Among 150 dry patellae, 92 were male (61.33%), and 58 were female (38.67%).

Permission to access the specimens was obtained from the heads of the Anatomy Departments at DMC, Northern International Medical College, and Ibn Sina Medical College. The study's objectives were explained to medical students, from whom the bones were temporarily borrowed. Measurements were recorded on structured data collection sheets, and all specimens were returned to the donors immediately following data recording. Ethical approval for the study was granted by the Institutional Ethical Review Committee (ERC).

To ensure accuracy despite the irregular posterior surface of the patella, specific measurements were taken using a flexible metallic wire, which was subsequently straightened and measured with a digital slide caliper. Other linear dimensions were recorded directly using a digital slide caliper. The apex angle was measured using a standard protractor. Patellar weight was measured using an electronic balance, and volume was determined via the water displacement method in a graduated glass cylinder. Data were audited, edited, and entered into Microsoft Excel before being analyzed using SPSS version 22.0. Descriptive statistics are reported as mean $\pm$ standard deviation (SD) and percentages. Sex-wise comparisons of continuous variables were performed using the unpaired Student's t-test. Statistical significance was set at $p < 0.05$.

Results

Male patellae were significantly larger than female patellae across all primary linear and volumetric measurements. Specifically, males exhibited greater height 42.10 ± 1.99 mm vs 36.16 ± 2.31 mm, width 42.87 ± 1.80 mm vs 36.94 ± 1.58 mm, thickness 20.73 ± 1.25 mm vs 18.69 ± 1.39 mm, weight 10.59 ± 2.13 g vs 6.79 ± 1.45 g, and volume 10.88 ± 1.98 cm³ vs 7.10 ± 1.34 cm³, all $p < 0.01$. Males also demonstrated significantly greater ridge height (29.90 ± 2.38 mm vs 26.89 ± 2.02 mm, $p < 0.01$) and larger articular facet widths. The lateral facet width was 25.00 ± 1.31 mm in males compared to 22.59 ± 1.73 mm in females, while the medial facet width was 21.61 ± 1.52 mm vs 18.32 ± 1.53 mm (both $p < 0.01$). Facet thicknesses were also slightly but significantly higher in males: medial 16.38 ± 1.06 mm vs 15.50 ± 1.55 mm ($p = 0.001$), lateral: lateral 13.91 ± 1.04 mm vs 13.16 ± 1.53 mm ($p = 0.002$). In contrast, females exhibited a significantly higher apex: $110.17 \pm 10.80^\circ$ vs $104.65 \pm 6.80^\circ$ ($p < 0.01$), and a higher lateral facet ratio: 0.61 ± 0.04 vs 0.58 ± 0.03 ($p < 0.01$). However, no significant differences were observed between the sexes for the following indices: patellar index (101.98 ± 5.07 vs 102.46 ± 5.90 , $p = 0.599$) and median ridge position (0.50 ± 0.03 vs 0.49 ± 0.04 , $p = 0.127$).

Table I

Sex-wise comparison of patellar morphometry, facet dimensions, and derived indices in dry human patellae (N = 150)

Variable, unit	Male (n=92), Mean $\pm$ SD (Range)	Female (n=58), Mean $\pm$ SD (Range)	P value
Maximum patellar height (mm)	42.10 ± 1.99 (37.50–46.70)	36.16 ± 2.31 (31.30–40.45)	0.001**
Maximum patellar width (mm)	42.87 ± 1.80 (39.20–46.35)	36.94 ± 1.58 (33.35–40.35)	0.001**
Maximum patellar thickness (mm)	20.73 ± 1.25 (17.27–26.60)	18.69 ± 1.39 (16.10–22.12)	0.001**
Height of median ridge (mm)	29.90 ± 2.38 (20.23–34.82)	26.89 ± 2.02 (22.35–35.00)	0.001**
Width of lateral articular facet (mm)	25.00 ± 1.31 (20.25–27.72)	22.59 ± 1.73 (18.02–25.60)	0.001**
Width of medial articular facet (mm)	21.61 ± 1.52 (19.10–25.41)	18.32 ± 1.53 (14.80–22.10)	0.001**
Medial facet thickness (mm)	16.38 ± 1.06 (13.04–18.32)	15.50 ± 1.55 (11.95–18.80)	0.001**
Lateral facet thickness (mm)	13.91 ± 1.04 (10.66–16.12)	13.16 ± 1.53 (10.40–16.60)	0.002**
Weight (g)	10.59 ± 2.13 (6.07–18.23)	6.79 ± 1.45 (3.13–9.92)	0.001**
Volume (cm ³)	10.88 ± 1.98 (7.0–16.3)	7.10 ± 1.34 (5.0–10.0)	0.001**
Angle of apex ($^\circ$)	104.65 ± 6.80 (90.0–120.0)	110.17 ± 10.80 (90.0–135.0)	0.001**
Patellar index	101.98 ± 5.07 (90.79–115.15)	102.46 ± 5.90 (88.80–115.87)	0.599 ^{ns}
Median ridge position	0.50 ± 0.03 (0.43–0.59)	0.49 ± 0.04 (0.43–0.63)	0.127 ^{ns}
Lateral facet ratio	0.58 ± 0.03 (0.49–0.65)	0.61 ± 0.04 (0.49–0.69)	0.001**

Comparison between sex was done by unpaired student's 't' test, N= total sample size, n= sample size in each groups, **= significant at the level of $P < 0.01$, ^{ns}= not significant.

Table II
Primary outcomes, apex angle and lateral facet ratio, sex-wise differences with 95% confidence intervals and effect sizes (N = 150)

Primary outcome	Male (n=92) Mean $\pm$ SD (Range)	Female (n=58) Mean $\pm$ SD (Range)	Mean difference (F-M)	95% CI for difference	Effect size (Hedges g)	P value
Angle of apex ($^{\circ}$)	104.65 $\pm$ 6.80 (90.0–120.0)	110.17 $\pm$ 10.80 (90.0–135.0)	5.52	2.37-8.67	0.64	0.001**
Lateral facet ratio	0.58 $\pm$ 0.03 (0.49–0.65)	0.61 $\pm$ 0.04 (0.49–0.69)	0.03	0.018-0.042	0.87	0.001**

N= total sample size, n= sample size in each groups, ** = significant at the level of $P < 0.01$

Apex angle showed weak positive correlation with both the lateral facet ratio ($r = +0.11$, $p = 0.167$) and the median ridge position ($r = +0.11$, $p = 0.185$); however, neither relationship reached statistical significance. Additionally, the apex angle exhibited a small, statistically significant negative correlation with lateral facet width ($r = -0.18$, $p = 0.026$) and a weak,

non-significant negative correlation with medial facet width ($r = -0.14$, $p = 0.079$). The lateral facet ratio demonstrated moderate and significant negative correlations with both the lateral facet width and the medial facet width ($r = -0.36$, $p < 0.01$). A moderate positive correlation was observed between the widths of the lateral and medial facets ($r = +0.46$, $p < 0.01$).

Table III
Correlation matrix of apex angle, lateral facet ratio, median ridge position, and articular facet widths (N = 150)

Variable	Apex angle ($^{\circ}$)	Lateral facet ratio	Median ridge position	Lateral facet width (mm)	Medial facet width (mm)
Apex angle ($^{\circ}$)	1	0.11 (0.167)	0.11 (0.185)	-0.18 (0.026)	-0.14 (0.079)
Lateral facet ratio	0.11 (0.167)	1	-0.03 (0.736)	-0.36 (<0.001)	-0.36 (<0.001)
Median ridge position	0.11 (0.185)	-0.03 (0.736)	1	-0.11 (0.191)	-0.06 (0.468)
Lateral facet width (mm)	-0.18 (0.026)	-0.36 (<0.001)	-0.11 (0.191)	1	0.46 (<0.001)
Medial facet width (mm)	-0.14 (0.079)	-0.36 (<0.001)	-0.06 (0.468)	0.46 (<0.001)	1

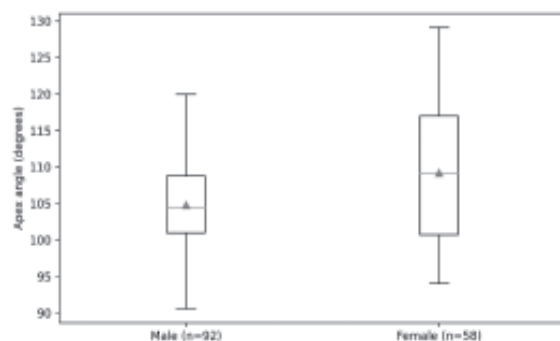


Fig.-2: Apex angle boxplot

The distribution is shifted upward in females, the median and mean, apex angle are higher in females

than males, with greater variability in females, consistent with the higher female mean ($110.17 \pm 10.80^{\circ}$) compared with males ($104.65 \pm 6.80^{\circ}$).

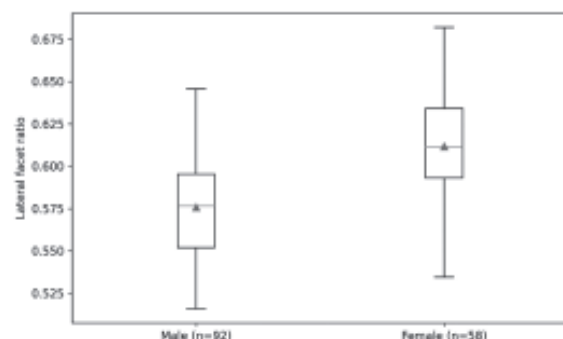


Fig.-3: Lateral facet ratio boxplot

Females show a higher central tendency for lateral facet ratio; the median and mean are above those of males, consistent with female values (0.61 ± 0.04) exceeding male values (0.58 ± 0.03), with a slightly wider spread among females.

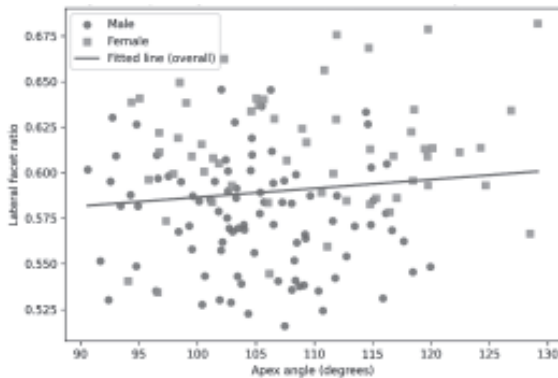


Fig.-4: Scatter plot, apex angle vs lateral facet ratio

The fitted line shows a weak positive relationship overall, meaning lateral facet ratio tends to increase slightly as apex angle increases, although the scatter is wide, indicating the association is small relative to between-specimen variability.

Discussion

The present morphometric analysis of 150 dry adult left patellae demonstrates clear sexual dimorphism following discriminant classification, with male specimens exhibiting significantly larger osteometric dimensions and mass. Compared to females, males had greater maximum height (42.10 ± 1.99 mm vs 36.16 ± 2.31 mm), width (42.87 ± 1.80 mm vs 36.94 ± 1.58 mm), and thickness (20.73 ± 1.25 mm vs 18.69 ± 1.39 mm); all $p < 0.01$. Differences in weight and volume followed a similar pattern ($p < 0.01$). This “males are larger” trend is consistent with contemporary morphologic research utilizing dry bone and imaging, including studies emphasizing sex differences in surgical sizing and forensic applications of patellar metrics.⁹⁻¹² At the retropatellar articular surface, males exhibited significantly larger facets, including greater lateral facet width (25.00 ± 1.31 mm vs 22.59 ± 1.73 mm), medial facet width (21.61 ± 1.52 mm vs 18.32 ± 1.53 mm), and increased facet thickness. The

observation that the lateral facet remained consistently wider than the medial facet aligns with prior anatomical evaluations and reinforces the concept that the lateral facet dominates retropatellar articulation.^{8,13} This is clinically significant because facet geometry dictates patellofemoral contact area and tracking, directly influencing lateral engagement during knee flexion.¹³ Interestingly, shape-related outcomes demonstrated a different pattern. Females exhibited a significantly higher apex angle ($110.17 \pm 10.80^\circ$) than males ($104.65 \pm 6.80^\circ$), with a medium effect size (Hedges $g = 0.64$). Females also showed a higher lateral facet ratio (0.61 ± 0.04 vs 0.58 ± 0.03), mean difference 0.03 (95% CI $0.018-0.042$), with a large effect size ($g = 0.87$), both $p < 0.01$. Recent statistical shape analysis supports these findings, suggesting that sexual dimorphism may be more pronounced in facet shape than in simple proportional indices.¹⁴ Furthermore, clinical studies on patellofemoral instability and trochlear dysplasia report that facet shape and geometry are implicated in altered engagement and lateral restraint mechanics, contextualizing why the apex angle and facet dominance are critical markers beyond absolute size.^{15,16} Notably, the patellar index and median ridge position did not differ significantly between sexes. This suggests that while absolute dimensions vary, height-width scaling and ridge location may be comparatively conserved. Our correlation findings support this; the apex angle showed only weak, non-significant associations with the lateral facet ratio and ridge position ($r = 0.11$, $p > 0.05$), whereas the lateral facet ratio correlated moderately and inversely with both facet widths ($r = -0.36$, $p < 0.01$), confirming that this ratio captures relative facet dominance rather than overall size.

The observed sex differences in thickness and facet geometry are highly relevant to patellar resurfacing, patellofemoral arthroplasty, and fracture fixation. Maintaining adequate residual bone stock and selecting component shapes that reproduce native facet geometry are primary determinants of proper tracking and the prevention of postoperative anterior knee pain. Evidence suggests that implant-bone mismatch contributes to persistent symptoms, reinforcing the need for anatomy-aware planning and potentially sex-specific sizing.^{18,19}

Conclusion

Male patellae were found to be significantly larger in overall dimensions, facet widths, thickness, weight, and volume compared to female patellae. In contrast, female patellae demonstrated a significantly higher apex angle and lateral facet ratio. Notably, the patellar index and median ridge position did not differ significantly between the sexes. These sex-related morphologic patterns provide robust reference data that may enhance patellofemoral surgical planning, facilitate more accurate implant sizing, and support future population-specific anatomical research.

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