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Original Article

Morphological Classification and Facet-Based Typing of Human Left Patella - A Descriptive Skeletal Study in a Bangladeshi Population

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Sheuli Akter[1*], Mustafezur Rahman[2], Mahmuda Khatoon[3], Roksana Begum[4]

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Sher-E-Bangla Medical College, Barishal, Bangladesh

*Corresponding Author

ABSTRACT

Background: *The patella is the largest sesamoid bone, crucial for knee joint biomechanics, yet little is known about its morphometry and facet-based classification in the Bangladeshi population. The current study aimed to evaluate sex-based morphometric differences and facet classification of the human left patella in a Bangladeshi skeletal sample.* ***Methods & Materials:*** *A total of 150 dry, fully ossified left patellae were analyzed. Linear dimensions (height, width, thickness, and facet widths) and derived ratios (width-to-height, width-to-thickness, height-to-thickness, facet ratios) were recorded. Sex was estimated using discriminant function analysis. Patellae were classified into Types A, B, and C based on articular facet widths. Statistical comparisons were performed using unpaired t-tests (p<0.05).* ***Results:*** *All measured dimensions were significantly higher in males (p<0.001) except the width-to-height ratio and median ridge position (p>0.05). Type B patellae (WMAF < WLAF) were predominant (87.3%), while Type C was absent. The lateral facet ratio was significantly higher in females (p<0.001).* ***Conclusion:*** *This study confirms significant sexual dimorphism and the dominance of Type B patellae in the Bangladeshi population. These findings provide valuable anatomical references for orthopedics, prosthetic design, and forensic sex estimation.*

Keywords: *Patella morphometry, Facet classification, Sexual dimorphism, Bangladeshi population, Orthopedic anatomy*

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1. *Assistant Professor, Department of Anatomy, Ibn Sina Medical College, Dhaka, Bangladesh*
2. *Consultant, Department of Gastroenterology, National Gastroliver Institute & Hospital, Dhaka, Bangladesh*
3. *Associate Professor, Department of Anatomy, Ibn Sina Medical College, Dhaka, Bangladesh*
4. *Assistant Professor, Department of Anatomy, United Medical College, Dhaka, Bangladesh*

INTRODUCTION

The patella, commonly referred to as the kneecap, is the largest sesamoid bone in the human body, embedded within the quadriceps femoris tendon and articulating with the femoral trochlea. Anatomically, it plays a critical role in the biomechanics of the knee joint by facilitating extension, stabilizing the extensor mechanism, and protecting the anterior articular surface of the femur [1]. Biomechanical studies show that the patella endures loads ranging from approximately 1.0 times body weight during level walking to over 7.0 times body weight during activities such as stair climbing or deep knee flexion [2]. This unique load-bearing function arises from the patella's ability to act as a pulley, increasing the moment arm of the quadriceps tendon and redistributing forces across the patellofemoral joint to enhance efficiency during knee extension [3,4]. Beyond its mechanical function, the patella is integral to maintaining joint congruency and reducing stress concentrations within the patellofemoral unit. Any alteration in its dimensions, facet structure, or articular alignment may lead to aberrant tracking, increased contact pressure, and symptomatic complications such as anterior knee pain or patellofemoral instability [5]. Even minor deviations in patellar width-to-height or facet asymmetry have been shown to significantly affect the kinematics of the joint, thereby influencing both performance and clinical outcomes in orthopedic interventions [6]. In addition, understanding the variability in lateral-to-medial facet proportions, thickness, and ridge position is essential for recognizing predispositions to degenerative changes, particularly among populations undergoing increased mechanical loading due to occupational or lifestyle-related activities. Morphological features of the patella—such as shape, size, and articular facet configuration—exhibit considerable inter-individual variability influenced by factors including age, sex, musculoskeletal loading, and ethnicity [7,8]. Several morphometric studies have underscored the existence of sexual dimorphism in patellar dimensions, with males generally exhibiting greater patellar height, width, and thickness, while ratios such as width/thickness or lateral-to-medial facet width remain relatively conserved across sexes [9,10]. This sexually dimorphic variation is believed to reflect both hormonal and mechanical influences on skeletal development, which manifest distinctly in long bones and sesamoid elements alike. Importantly, such morphological patterns have implications in multiple domains, including biomechanics, forensic anthropology, and prosthetic design. In orthopedic surgery, particularly total knee arthroplasty (TKA), accurate morphometric understanding of the patella is essential for proper implant selection and patellar resurfacing. Numerous studies have shown that improper matching of implant dimensions to patellar morphology can lead to complications such as maltracking, implant loosening, anterior knee pain, and even periprosthetic fractures [11-13].

Given that the patella lacks periosteum, its regenerative potential is limited, and any deviation in its mechanical or anatomical alignment post-surgery may adversely affect rehabilitation outcomes [14]. Furthermore, an understanding of facet configuration and ridge position is indispensable for resurfacing strategies, which must preserve functional articular congruence to maintain extensor mechanics and joint longevity. In forensic anthropology, the patella has emerged as a viable bone for sex estimation, especially in cases where pelvic or cranial remains are unavailable. Discriminant function analyses using patellar height, width, and thickness have yielded classification accuracies ranging from 80% to over 90% in various populations, making it a robust tool for skeletal identification [15–17]. Recent computational models and radiographic studies further confirm the reliability of patellar measurements in multivariate sex prediction, especially when combined with 3D imaging modalities [18]. Notably, there is considerable global heterogeneity in patellar morphometry. For example, Shang et al. reported significantly smaller and thinner patellae among southern Chinese individuals compared to Western norms, while South African populations demonstrated high prevalence of Type B patellae and significant sex-based variation in facet widths [19,20]. Indian studies likewise confirm predominance of Type B patterns with large lateral facets and comparatively smaller medial facets in populations from Bengal, Rajasthan, and Tamil Nadu [21,22]. Despite such extensive documentation in neighboring and global cohorts, Bangladesh lacks any peer-reviewed, population-specific data on patellar morphometry, facet-based typing, or morphometric sexual dimorphism. This absence of national baseline data is concerning, especially considering the growing volume of total knee replacement procedures and orthopedic interventions in the country. In such scenarios, reliance on external anatomical references may result in suboptimal implant design, surgical mismatch, and impaired functional recovery. Given these realities, it becomes imperative to conduct localized morphometric analyses that reflect the skeletal nuances of the Bangladeshi population.

METHODS & MATERIALS

This cross-sectional analytical study was conducted in the Department of Anatomy at Dhaka Medical College, Dhaka, from January 2018 to June 2019. A total of 150 fully ossified dry adult human left patellae of unknown sex were collected through convenient purposive sampling from medical students and anatomical collections at Dhaka Medical College, Northern International Medical College, and Ibn Sina Medical College. Patellae showing deformities, fractures, or incompleteness were excluded. Sex determination was carried out using multivariate linear discriminant function analysis based on maximum height (MAXH) and maximum width (MAXW) of the patellae, allowing classification into male and female groups. Following this, 92 specimens were classified as male and 58 as female. Morphometric variables were measured using digital slide calipers, protractors, and flexible metallic wire. Volume was calculated by the water displacement method, and weight was measured using an electronic balance. A total of eleven linear variables were measured, including MAXH, MAXW, thickness, medial and lateral facet widths and thicknesses, and height of the median ridge. Additionally, six indices were calculated: patellar index, width/height ratio, width/thickness ratio, height/thickness ratio, position of the median ridge, and lateral facet ratio. The shape, type (A/B/C based on facet symmetry), and nose pattern of the patellae were also observed. All measurements were taken three times and averaged for accuracy. Statistical analysis was performed using SPSS version 22.0. Descriptive statistics were expressed as mean ± SD, and group comparisons were conducted using unpaired Student's t-test, with statistical significance set at $p<0.05$. Ethical clearance was obtained from the Institutional Ethical Review Committee of Dhaka Medical College.

RESULTS

Male patellae demonstrated significantly greater maximum height (42.10 ± 1.99 mm) and width (42.87 ± 1.80 mm) compared to female patellae (36.16 ± 2.31 mm and 36.94 ± 1.58 mm, respectively), with both parameters showing highly significant differences ($p<0.001$). The overall mean values were 39.68 mm in height and 40.56 mm in width across all specimens. [Table I]

Table – I: Maximum Patellar Height and Width in Male and Female (*n* = 150)

Variable	Male (n = 92)	Female (n = 58)	Total (N = 150)	p-value
Max Patellar Height (mm)	42.10 ± 1.99 (37.50–46.70)	36.16 ± 2.31 (31.30–40.45)	39.68 ± 3.85 (31.30–46.70)	<0.001*
Max Patellar Width (mm)	42.87 ± 1.80 (39.20–46.35)	36.94 ± 1.58 (33.35–40.35)	40.56 ± 3.59 (33.35–46.35)	<0.001*

*Note: Values are expressed as mean ± standard deviation (range); *Comparison between male and female was done using unpaired Student's t-test; *Statistical significance considered at p<0.05.*

The mean patellar thickness and height of the median ridge were significantly higher in males (20.73 ± 1.25 mm and 29.90 ± 2.38 mm, respectively) compared to females (18.69 ± 1.39 mm and 26.89 ± 2.02 mm). These differences were statistically significant ($p<0.001$), indicating pronounced posterior and sagittal dimensional differences between sexes. [Table II]

Table – II: Maximum Patellar Thickness and Height of Median Ridge in Male and Female (*n* = 150)

Variable	Male (n = 92)	Female (n = 58)	Total (N = 150)	p-value
Max Patellar Thickness (mm)	20.73 ± 1.25 (17.27–26.60)	18.69 ± 1.39 (16.10–22.12)	19.97 ± 1.61 (16.10–26.60)	<0.001*
Height of Median Ridge (mm)	29.90 ± 2.38 (20.23–34.82)	26.89 ± 2.02 (22.35–35.00)	28.68 ± 2.49 (20.23–35.00)	<0.001*

*Note: Values are expressed as mean ± standard deviation (range); *Comparison between male and female was done using unpaired Student's t-test; *Statistical significance considered at p<0.05.*

The width of both lateral and medial articular facets was consistently greater in male patellae (25.00 ± 1.31 mm and 21.61 ± 1.52 mm) than in female patellae (22.59 ± 1.73 mm and 18.32 ± 1.53 mm). These inter-sex differences were statistically significant (p<0.001), suggesting stronger lateral-medial dimensional asymmetry in males. [Table III]

Table – III: Width of Lateral and Medial Articular Facets of Patella in Male and Female (*n* = 150)

Variable	Male (n = 92)	Female (n = 58)	Total (N = 150)	p-value
Width of Lateral Articular Facet (mm)	25.00 ± 1.31 (20.25–27.72)	22.59 ± 1.73 (18.02–25.60)	24.08 ± 1.89 (18.02–27.72)	<0.001*
Width of Medial Articular Facet (mm)	21.61 ± 1.52 (19.10–25.41)	18.32 ± 1.53 (14.80–22.10)	20.29 ± 2.07 (14.80–25.41)	<0.001*

*Note: Values are expressed as mean ± standard deviation (range); *Comparison between male and female was done using unpaired Student's t-test; *Statistical significance considered at p<0.05.*

Facet-based classification revealed a marked predominance of Type B patellae (WMAF < WLAF), found in 87.3% of total cases (84.8% in males and 91.4% in females). Type A patellae (WMAF = WLAF) accounted for 12.7% overall, while Type C (WMAF > WLAF) was absent in all specimens, reflecting a consistent asymmetric facet morphology across sexes. [Table IV]

Table – IV: Morphological Facet-Based Typing of Left Patella by Sex (*n* = 150)

Type of Patella	Definition	Male (n = 92)	Female (n = 58)	Total (N = 150)
Type A	WMAF = WLAF	14 (15.2%)	5 (8.6%)	19 (12.7%)
Type B	WMAF < WLAF	78 (84.8%)	53 (91.4%)	131 (87.3%)
Type C	WMAF > WLAF	0 (0.0%)	0 (0.0%)	0 (0.0%)

Note: WMAF = Width of Medial Articular Facet; WLAF = Width of Lateral Articular Facet; Type classification is based on comparative facet width measurements.

Type B patellae, characterized by a narrower medial facet (WMAF < WLAF), constituted the majority of the sample at 87.3%. Type A patellae, where medial and lateral facet widths were equal (WMAF = WLAF), accounted for 12.7%. No Type C patellae (WMAF > WLAF) were observed. [Figure 1]

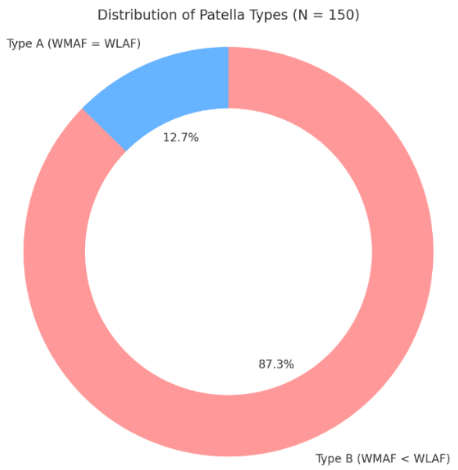

Figure – 1: Distribution of Patella Types (*n* = 150)

The width-to-height ratio was comparable between sexes (p=0.772), indicating no significant difference. However, the width-to-thickness and height-to-thickness ratios were both significantly higher in males (2.07 ± 0.15 and 2.03 ± 0.10, respectively) than in females (1.98 ± 0.12 and 1.92 ± 0.15), with p-values <0.001. These ratios reflect proportionate differences in transverse and sagittal dimensions. [Table V]

Table – V: Morphometric Ratios of the Patella in Male and Female (*n* = 150)

Ratio	Male (n = 92)	Female (n = 58)	Total (N = 150)	p-value
Width/Height Ratio	1.01 ± 0.05 (0.90–1.15)	1.02 ± 0.06 (0.88–1.15)	1.01 ± 0.06 (0.88–1.15)	0.772ns
Width/Thickness Ratio	2.07 ± 0.15 (1.10–2.50)	1.98 ± 0.12 (1.63–2.23)	2.04 ± 0.15 (1.10–2.50)	<0.001*
Height/Thickness Ratio	2.03 ± 0.10 (1.77–2.34)	1.92 ± 0.15 (1.20–2.30)	1.99 ± 0.13 (1.20–2.34)	<0.001*

Note: Values are expressed as mean ± standard deviation (range); *Comparison between male and female was done using unpaired Student's t-test; *Statistical significance considered at p<0.05; ns = not significant.

There was no statistically significant difference in the position of the median ridge between males and females (p=0.127), with a pooled mean ratio of 0.50 ± 0.03. However, the lateral facet ratio was significantly higher in females (0.61 ± 0.04) than in males (0.58 ± 0.03), with a p-value <0.001, indicating sex-related differences in lateral facet dominance. [Table VI]

Table – VI: Median Ridge Position and Lateral Facet Ratio of Patella in Male and Female (*n* = 150)

Variable	Male (n = 92)	Female (n = 58)	Total (N = 150)	p-value
Median Ridge Position	0.50 ± 0.03 (0.43–0.59)	0.49 ± 0.04 (0.43–0.63)	0.50 ± 0.03 (0.43–0.63)	0.127ns
Lateral Facet Ratio	0.58 ± 0.03 (0.49–0.65)	0.61 ± 0.04 (0.49–0.69)	0.59 ± 0.04 (0.49–0.69)	<0.001*

*Note: Median ridge position = distance from medial border to ridge ÷ total patellar width; Lateral facet ratio = width of lateral facet ÷ total patellar width; Values are expressed as mean ± standard deviation (range); Statistical comparisons were made using unpaired Student's t-test; *Statistical significance considered at p<0.05; ns = not significant.*

DISCUSSION

The present morphometric analysis of the human left patella in a Bangladeshi skeletal sample provides critical insights into sex-related anatomical variations, articular facet configuration, and proportional indices that are clinically and anthropologically significant. Our findings revealed a significantly greater maximum patellar height and width in males (42.10 ± 1.99 mm and 42.87 ± 1.80 mm) than in females (36.16 ± 2.31 mm and 36.94 ± 1.58 mm), reflecting a strong degree of sexual dimorphism (p<0.001). This aligns closely with studies conducted on Egyptian, Nepalese, and Southern Chinese populations, where males consistently showed larger patellar dimensions than females [19,23,24]. The pooled mean height (39.68 mm) and width (40.56 mm) in our study are also in agreement with those reported for South Asian and Southeast Asian cohorts [25]. Patellar thickness, another critical structural variable, also exhibited significant sex-based disparity in our study, with males presenting a thicker patella (20.73 ± 1.25 mm) compared to females (18.69 ± 1.39 mm). This finding is supported by studies from Nepal and South Bengal that similarly noted higher patellar thickness in males [22,24]. In terms of posterior surface elevation, the height of the median ridge was significantly higher in males (29.90 ± 2.38 mm) versus females (26.89 ± 2.02 mm), although literature focusing specifically on ridge height is sparse. Nevertheless, the general finding of central ridge prominence has been corroborated in cadaveric studies such as those by Tanpowpong et al., and Agarwal et al [26,27]. Our results also highlighted significant sex-based differences in articular facet morphology. The width of the lateral articular facet in males (25.00 ± 1.31 mm) was notably larger than in females (22.59 ± 1.73 mm), with similar trends for the medial facet (21.61 ± 1.52 mm vs. 18.32 ± 1.53 mm), all p-values <0.001. These findings are consistent with previous investigations by Doshi et al., Medeiros et al., and Wilson et al., who similarly found dominance of the lateral facet over the medial facet in both sexes [7,8,28]. The global prevalence of such asymmetry further substantiates our classification results, where Type B patellae (WMAF < WLAF) were predominant (87.3% overall). This predominance is well-supported by studies from India and Brazil, both reporting a majority of Type B patterns with minimal or absent representation of Type C [21,28]. In the assessment of morphometric ratios, our findings demonstrated that while the width-to-height ratio showed no statistically significant sex difference (p=0.772), the width-to-thickness and height-to-thickness ratios were significantly greater in males (2.07 and 2.03, respectively) than in females (1.98 and 1.92). These findings are in line with the Bristol Index and studies from the UK and Japan, which emphasized the surgical importance of maintaining natural width/thickness proportions to prevent patellar malalignment or prosthesis mismatch [9,29]. The pooled mean width-to-thickness ratio in our study (2.04 ± 0.15) aligns closely with the universal reference value of approximately 2.0, suggesting anatomical consistency across populations despite slight regional variations [30]. Interestingly, no significant difference was observed in the position of the median ridge between sexes (p=0.127), with a mean value of 0.50 ± 0.03, indicating its relatively central location. This observation is comparable to intraoperative studies by Baldwin & House; and dry bone evaluations by Agarwal et al., both of which reported minimal sex-based differences in dome position or ridge alignment [27,31]. On the other hand, the lateral facet ratio was significantly higher in females (0.61 ± 0.04) compared to males (0.58 ± 0.03), suggesting a relatively broader lateral articular surface in females. Wilson et al. also highlighted such sex-specific differences in lateral facet configuration, particularly noting increased shape variance and surface area in female patellae, which may have implications for joint biomechanics and prosthetic design [7]. Taken together, our findings reaffirm the morphological asymmetry and sexual dimorphism of the patella as a consistent anatomical pattern observed across various global populations. However, the specific values and proportions found in our Bangladeshi cohort provide much-needed localized reference data, which has thus far been absent from indexed literature. These results can directly inform orthopedic practice, particularly in improving implant sizing accuracy for patellofemoral interventions in Bangladeshi patients, and enhance forensic anthropological applications in regional identification.

Limitations of The Study

This study was limited to dry, left-sided patellae of unknown age and was conducted within a single geographic region of Bangladesh, which may not fully represent national anatomical variation. Additionally, the absence of radiological correlation or in vivo measurements may restrict clinical extrapolation in surgical practice. The sex of the specimens was determined using morphometric discriminant analysis rather than confirmed biological records, which may introduce some degree of classification bias.

CONCLUSION

This morphometric and facet-based analysis of the human left patella in a Bangladeshi population reveals significant sexual dimorphism in nearly all linear and proportional dimensions, with males exhibiting consistently higher values for height, width, thickness, and facet measurements. The predominance of Type B patellae and the asymmetrical distribution of lateral and medial facets align with regional and global findings, highlighting a conserved morphological pattern. Importantly, the study offers localized normative data that can support orthopedic implant design, enhance the accuracy of sex estimation in forensic investigations, and contribute to anatomical reference databases for South Asian populations.

RECOMMENDATION

We recommend that future studies incorporate larger and more diverse Bangladeshi populations, include both radiological and cadaveric samples, and evaluate bilateral symmetry. Development of standardized, population-specific patellar implant templates and use of these morphometric references in forensic identification protocols are strongly encouraged.

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