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Patellar Morphology and Its Clinical Implications for Patellofemoral Syndrome: An Anatomical Study

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ABSTRACT
Introduction: the patella is a sesamoid bone embedded within the tendon of the quadriceps femoris and plays a critical role in knee biomechanics by enhancing the leverage of the extensor mechanism and protecting the anterior aspect of the knee joint. Variations in patellar morphology have been implicated as contributing factors in patellofemoral syndrome (PFS), a common cause of anterior knee pain. Despite the high prevalence of PFS, there remains no consensus regarding its precise pathophysiology, and anatomical factors continue to be investigated. The present study aimed to analyze the morphology of adult human patellae, propose a morphological classification, and provide quantitative measurements that may contribute to clinical and biomechanical understanding. Thirty-seven patellae from adult human skeletons housed in the Anatomy Laboratory of the Ribeirão Preto Medical School, University of São Paulo, were analyzed. Based on visual inspection, patellae were classified into three morphological types: type I (triangular), type II (oblong), and type III (irregular). Morphometric parameters were obtained using a stainless steel caliper, including longitudinal diameter, base width, medial and lateral articular surface diameters, and the length of the non-articular surface. Type I patellae were the most prevalent (67.6%), followed by type II (21.6%) and type III (10.8%). Statistical analysis revealed significant asymmetries between right and left patellae and differences between morphological types, particularly regarding longitudinal diameter. These findings reinforce the relevance of patellar morphology in knee biomechanics and suggest that anatomical variation should be considered in the evaluation and management of patellofemoral disorders.
Keywords: Patella; Morphology; Sesamoid bone; Patellofemoral syndrome; Knee anatomy.

Introduction

The patella is the largest sesamoid bone in the human body and is located anterior to the knee joint, embedded within the tendon of the quadriceps femoris muscle. Its primary biomechanical functions include protection of the anterior knee structures and optimization of the mechanical advantage of the quadriceps muscle during knee extension[1]. By increasing the moment arm of the extensor mechanism, the patella plays a decisive role in gait, posture, and load transmission across the knee joint.

Patellofemoral syndrome (PFS) is one of the most frequent causes of anterior knee pain, particularly among young and physically active individuals[2]. Clinically, PFS is characterized by pain exacerbated by activities that increase patellofemoral joint reaction forces, such as stair climbing, squatting, or prolonged sitting with knee flexion. Although the clinical presentation of PFS is well recognized, its etiology is considered multifactorial and remains incompletely understood.

Among the factors associated with PFS, patellar tracking, alignment, and morphology have received increasing attention. Variations in patellar shape and size may influence the distribution of contact stresses on the femoral trochlea and alter the biomechanics of the patellofemoral joint[4]. Nevertheless, normative data on patellar morphology remain limited, particularly in anatomical collections representative of diverse populations.

Therefore, the aim of this study was to analyze the morphology of adult human patellae, establish a simple morphological classification, and provide morphometric data that may contribute to the anatomical and clinical understanding of patellofemoral biomechanics.

Materials and Methods

This descriptive anatomical study was conducted using dry skeletal material from the Anatomy Laboratory of the Ribeirão Preto Medical School, University of São Paulo, Brazil. A total of 37 adult

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human patellae of known laterality were selected. Patellae presenting fractures, deformities, or signs of pathological alteration were excluded from the analysis.

Morphological Classification

Each patella was initially evaluated by visual inspection and classified according to its overall shape into one of three categories (Figure 1):

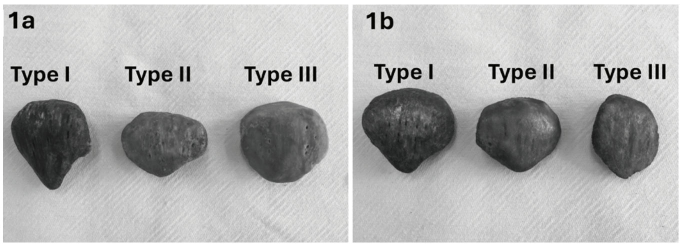

Figure 1. Examples of right (a) and left (b) patellae, classified as Type I, Type II, and Type III according to their morphology and measurements.

- **Type I (Triangular):** classic triangular shape with a well-defined apex and broad base;
- **Type II (Oblong):** elongated shape with reduced prominence of the apex;
- **Type III (Irregular):** asymmetrical or atypical morphology not fitting the previous categories.
- **Morphometric Analysis**

Morphometric measurements were obtained using a stainless steel digital caliper with a measuring range of 0–300 mm and a resolution of 0.01 mm. The following parameters were recorded (Figure 2):

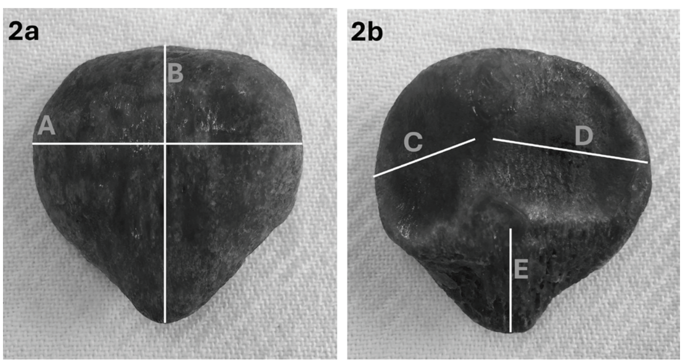

Figure 2. a: Typical Type I right patella, showing the non-articular surface and indicating the measurement locations. A = transverse diameter. B = longitudinal diameter. b: Typical Type I right patella, showing the articular surface and indicating the measurement locations. C = diameter of the medial articular facet. D = diameter of the lateral articular facet. E = length of the non-articular surface.

A. Base width: maximum mediolateral diameter at the base;

B. Longitudinal diameter: maximum distance from the base to the apex of the patella;

C. Medial articular surface diameter;

D. Lateral articular surface diameter;

E. Length of the non-articular surface.

All measurements were performed twice by the same observer, and the mean value was used for analysis.

Statistical Analysis

Descriptive statistics were calculated for all variables. Comparative analyses between right and left patellae and between morphological types were performed using appropriate statistical tests, with significance set at $p < 0.05$. Statistical analysis of type III patellae was limited due to the small sample size.

Results

Of the 37 patellae analyzed, 25 (67.6%) were classified as type I, 8 (21.6%) as type II, and 4 (10.8%) as type III. Type I patellae were therefore the most prevalent morphological pattern in the studied sample. When comparing right and left sides, Type I patellae were most prevalent on the left side (74%) compared to the right side (61%). For Type II patellae, they were more prevalent on the right side (28%) compared to the left side (16%). Type III patellae presented the same prevalence (11%) on both right and left sides.

In type I patellae, both the longitudinal diameter (right: 3.59 ± 0.40 cm, n = 11; left: 3.28 ± 0.26 cm, n = 14) and the base width (right: 3.76 ± 0.27 cm; left: 3.49 ± 0.34 cm) were significantly greater on the right side compared with the left. For both sides, the lateral articular surface diameter (right patella: 1.82 ± 0.13 cm; left patella: 1.72 ± 0.23 cm) was larger than the medial articular surface diameter (right patella: 1.33 ± 0.14 cm; left patella: 1.16 ± 0.20 cm). Additionally, the medial articular surface of the right patella (1.33 ± 0.14 cm) was significantly larger than that of the left (1.16 ± 0.20 cm).

When comparing type I and type II patellae, the longitudinal diameter was significantly greater in type I patellae (right side: 3.59 ± 0.40 cm vs. 2.85 ± 0.32 cm, n = 5; left side: 3.28 ± 0.26 cm vs. 2.87 ± 0.06 cm, n = 3), whereas no significant difference was observed in base width (right side: 3.76 ± 0.27 cm vs. 3.53 ± 0.36 cm; left side: 3.49 ± 0.34 cm vs. 3.41 ± 0.21 cm). Due to the limited number of specimens, statistical analysis of type III patellae was not performed (right side, n = 2: longitudinal diameter 3.09 cm and 3.15 cm, base width 3.44 cm and 3.45 cm; left side, n = 2: longitudinal diameter 3.09 cm and 3.27 cm, base width 2.93 cm and 3.27 cm).

Discussion

The predominance of triangular (type I) patellae observed in this study is consistent with classical anatomical descriptions[1]. As a sesamoid bone, the patella develops within the quadriceps tendon and is subjected predominantly to longitudinal tensile forces, which may explain the higher frequency of a triangular morphology with a prominent apex.

The observed asymmetry between right and left patellae, particularly regarding larger dimensions on the right side, may be related to functional dominance. Given that approximately 90% of the population is right-handed, increased mechanical loading on the dominant lower limb may influence bone modeling and remodeling throughout life[4].

Differences between type I and type II patellae were mainly related to longitudinal diameter, while base width remained similar. This finding suggests that the distinguishing feature between these two morphological types is the prominence of the patellar apex rather than overall width. Such variation may have biomechanical implications, as apex morphology can influence patellar tracking and contact mechanics within the femoral trochlea[5].

Regarding laterality, our findings diverge from those reported by Medeiros *et al.*[6] who analyzed 59 dry patellae from a Northeastern Brazilian population and found no significant difference between the right and left sides for either the medial articular facet (18.20±0.52 mm vs. 18.71±0.51 mm, p=0.48) or the lateral articular facet (24.49±0.34 mm vs. 23.88±0.51 mm, p=0.33), concluding that laterality did not directly affect patellar morphology. In contrast, our type I sample demonstrated a significant right-side predominance in longitudinal diameter, base width, and medial articular surface diameter. This discrepancy may reflect differences in sample size, in the specific parameters measured (facet width alone versus multiple linear diameters), or genuine population-level variation, and warrants further investigation with larger cohorts.

Despite this divergence, our results align with Medeiros *et al.*[6] regarding the relative proportions of the articular facets: in both studies, the lateral facet was consistently larger than the medial facet, a pattern that held even among type I specimens in our sample, despite Wibeeg's original description[7] characterizing type I facets as approximately equal in size. This reinforces the observation, also noted by Medeiros *et al.*[6], that true facet equality may be uncommon in practice even within nominally "type I" classifications.

The scarcity of type III patellae in our sample — precluding formal statistical analysis — is consistent with prior reports. Medeiros *et al.*[6] identified no type III specimens among 59 patellae, while Wibeeg[7] reported only 1 (4%) and Calderon *et al.*[8] reported 5 (6.6%), in contrast to the considerably higher prevalence (19%) described by Reider *et al.*[9]. This pattern suggests that type III morphology may be inherently rare in adult dry-bone samples, regardless of population.

Finally, our comparison of longitudinal diameter and base width between type I and type II patellae extends beyond the parameters reported by Medeiros *et al.*[6], who assessed only facet widths without stratifying linear dimensions by Wiberg type. The significantly greater longitudinal diameter observed in type I patellae, without a corresponding difference in base width, offers an additional dimension for characterizing morphological variation between types that has not been previously described in the regional literature.

Understanding patellar morphology is particularly relevant in the context of PFS, where altered patellofemoral contact stresses are thought to play a central role. Anatomical variation should therefore be considered during clinical assessment, imaging interpretation, and surgical planning involving the patellofemoral joint.

Conclusion

This anatomical study demonstrates that the triangular patella is the most prevalent morphological type in adult human skeletons. Significant morphometric differences exist between sides and among morphological types, particularly regarding longitudinal diameter. These findings reinforce the importance of considering patellar morphology in biomechanical analyses and in the clinical evaluation of patellofemoral disorders.

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Ethics statement

The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human cadaveric donors in anatomical research (Iwanaga *et al.*, 2022).

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