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# Comparative analysis of patellofemoral anthropometry by gender using magnetic resonance imaging

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**Abstract:** Patellofemoral instability affects women more often than men. Anatomical differences between the sexes lead to disturbances in patellofemoral alignment. Some of the key structural factors that contribute to patellar instability include trochlear dysplasia, patella alta, an increased tibial tuberosity-trochlear groove (TT-TG) distance, and lateral tilt of the patella. The study was conducted at a tertiary hospital. Patients with a history of patellar instability, history of fracture in the knee area, lower extremity deformity, history of knee ligament surgery and hyperlaxity were excluded. A total of 86 knee MRIs (45 men and 41 women) performed measurements of trochlear profile, patellar position, lateralization of the tibial tuberosity and patellar profile. Data were analyzed using descriptive and analytical analysis in the form of an Independent T-Test with the alternative Mann Whitney U-Test. The results of the study show significant differences between groups. There were differences in facet asymmetry ($p<0.02$), the depth of the trochlea ($p<0.03$), the Insall Salvati Index ($p<0.01$), the Caton Deshcamp Index ($p<0.01$), the bisection of the index ($p<0.01$), the Tibial Tuberosity-Posterior Cruciate Ligament (TT-PCL) ($p<0.016$), and the profile of the patella (Cranio Caudal Length, Transverse Length, Anteroposterior Length, Circumference, and Patellar Area) ($p<0.001$). Patellofemoral anthropometry shows significant gender differences. In women, a shallower trochlear groove, wider lateral facets, a higher and more lateral patellar position, and a smaller patellar profile are observed. These factors may contribute to the higher susceptibility of women to patellofemoral instability.

***Keywords:*** *Anthropometric, Gender, Magnetic resonance imaging, Medicine, Patellofemoral.*

## 1. Introduction

Patellofemoral instability is more frequently reported in women than in men due to anatomical differences between the genders that affect patellofemoral alignment. These variations include a higher prevalence of trochlear dysplasia, patella alta, an increased Q-angle, and greater soft tissue imbalances. As a result, women are at an increased risk for postoperative complications and recurrent dislocations or instability [1].

Several anthropometric parameters associated with patellar tracking in patients with stable and unstable patellae have been studied. Patellar tracking describes the dynamic interaction between the patella and the trochlea during knee movement. An imbalance in this relationship can trigger patellar maltracking, which is linked to geometric characteristics such as sulcus angles, facet asymmetry, and lateral trochlear inclination (LTI). [2, 3] The bisect offset index (BOI) and patellar lateral tilt (PLT) are also important parameters that indicate lateral shift and patellar tilt. The tibial tuberosity-trochlear groove (TT-TG) distance is used to evaluate the lateral movement of the patella relative to the tibial tuberosity.[4] The most important anatomical factors include trochlear dysplasia, increased TT-TG


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distance, patellar lateral tilt and patella alta.[2, 3] Patella alta describes an abnormally elevated patella in conjunction with the trochlea, which leads to decreased contact between the patella and the femoral area. it has been shown to correlate with patellofemoral pain and patellar instability.

MRI is the preferred imaging technique for assessing anterior knee pain because of the knee's complex structure and biomechanics, and it is also valuable for evaluating and predicting patellar maltracking. MRI imaging can measure these parameters and provide an overview of the soft tissue structures associated with patellar maltracking.[2] Recurrent patella instabilities are conditions that can lead to articular and osteochondral cartilage injury, patella pain, decreased activity, and patellofemoral osteoarthritis.[5] This condition is often undetected, especially in individuals who have not shown any symptoms. Understanding the benefits of patellar tracking is crucial, particularly for early detection. This study aims to identify patellofemoral morphology based on gender, examine the differences, and provide an initial description of how women tend to experience patellofemoral instability.

## 2. Methods

This quantitative research with a cross-sectional study with analytical design. The study will involve the identification of the trochlear profile, patellar position, lateralization of the tibial tuberosity, and patellar profile in patients with stable patellofemoral conditions at Dr. Soetomo Surabaya Hospital from 2019 to 2023.

The inclusion and exclusion criteria were applied to all data. The exclusion criteria included patients with a history of patellar dislocation, knee fractures, lower extremity deformities, previous knee ligament reconstruction surgery, and hyperlaxity. The study included patients with ACL injuries, either partial or total ruptures, who underwent MRI examinations. All participants were required to be at least 18 years old.

The data measurements are organized into four groups. The first group covers the trochlear profile, which includes the sulcus angle, facet asymmetry, trochlear depth, and lateral trochlear inclination. The second group focuses on patellar position, incorporating the Insall-Salvati Index, Caton-Deschamps Index, and bisect offset index. The third group addresses the lateralization of the tibial tuberosity, including the tibial tuberosity–trochlear groove distance, tibial tuberosity–posterior cruciate ligament distance, and patellar tendon–posterior cruciate ligament distance. The fourth group covers the patellar profile, which includes cranio-caudal length, transverse length, anteroposterior length, circumference, and patellar area.

The data will be processed manually and statistically analysis using the Statistical Package for the Social Sciences (SPSS). The Kolmogorov-Smirnov test will assess the data to determine its normal distribution. Furthermore, analysis will be conducted using the independent t-test and the alternative Mann-Whitney U test based on gender groups.

## 3. Results

This study obtained knee MRIs from 86 patients, consisting of 45 males and 41 females. The average age was 24.48 ± 7.8 (18-66) years. The trochlear profiles in both groups were compared using both descriptive and analytical analysis methods. Independent T-Test with alternative Mann Whitney U-test. As shown in Table 1, the average trochlear profile in the male group was higher than in the female group for sulcus angle (SA), facet asymmetry (FA), trochlear depth (TD) and lateral trochlear inclination (LTI) were higher. However, significant differences were only found in Facet Asymmetry and Trochlear Depth ($p<0.05$). These findings indicate that women's trochlear profiles are shallower, with a wider lateral trochlear facet.

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**Table 1.**
Comparison of trochlea profiles by gender

| | Male (45) | | Female (41) | | P value |
|---|---|---|---|---|---|
| | Mean ± SD | Range | Mean ± SD | Range | |
| SA (°) | 138.06 ± 2.80 | 126.9 – 142.74 | 137.78 ± 3.64 | 126.9 – 144.74 | 0.805† |
| FA (%) | 0.65 ± 0.108 | 0.40 – 0.89 | 0.59 ± 0.11 | 0.40 – 0.87 | 0.02* |
| TD (mm) | 6.04 ± 1.05 | 4,2 – 8.5 | 5.4 ± 1.04 | 3.2 – 8.3 | 0.03† |
| LTI (°) | 23.99 ± 4.09 | 16.35 – 39.45 | 22.82 ± 3.65 | 15.03 – 30.38 | 0.207† |

**Note:** *Analysis using Independent T-Test
*Analysis using Independent T-Test
†Analysis using Mann-Whitney U Test

**Table 2.**
Comparison of patella position by gender.

| | Male (45) | | Female (41) | | P value |
|---|---|---|---|---|---|
| | Mean ± SD | range | Mean ± SD | Range | |
| PLT (°) | 6.33 ± 3.93 | 0.59 – 15.07 | 8.20 ± 5.88 | -5.39 – 20.15 | 0.084* |
| ISI | 0.95 ± 0.158 | 0.61 – 1.27 | 1.08 ± 0.122 | 0.81 – 1.46 | <0.001* |
| CDI | 0.98 ± 0.131 | 0.70 – 1.22 | 1.10 ± 0.12 | 0.86 – 1.34 | <0.001* |
| BOI (%) | 0.55 ± 0.077 | 0.35 – 0.68 | 0.61 ± 0.097 | 0.45 – 0.83 | <0.001* |

**Note:** Analysis using Independent T-Test.

In the comparison of patellar position, as shown in Table 2, the average measurement of patellar position was highest in the female group. Significant differences were found in the Insall-Salvati Index (ISI), Caton-Deschamps Index (CDI), and bisect offset index (BOI) ($p < 0.05$). This comparison indicates that in the female group, there is a tendency toward high patella, and the position of the patella is more lateral when compared to the trochlear groove.

The comparison of tibial tuberosity lateralization is presented in Table 3, where the average tibial tuberosity lateralization is one of the three highest parameters in the male group. A significant difference was found in the TT-PCL parameter. This indicates that in women, there is no tendency for the tibial tuberosity to be located more laterally.

**Table 3.**
Tibial tuberosity lateralisation.

| | Male (45) | | Female (41) | | P value |
|---|---|---|---|---|---|
| | Mean ± SD | range | Mean ± SD | Range | |
| TT-TG (mm) | 14.59 ± 6.85 | 4.45 – 32.8 | 13.39 ± 5.02 | 5.88 – 25.6 | 0.610† |
| TT- PCL (mm) | 17.27 ± 4.64 | 7.01 – 29.2 | 15.11 ± 3.34 | 6.72 – 20.95 | 0.016* |
| PT-PCL (mm) | 37.88 ± 10.57 | 13.57 – 62.1 | 36.29 ± 288 | 14.62 – 52.1 | 0.444* |

**Note:** *Analysis using Independent T-Test.
†Analysis using Mann-Whitney U Test.

The comparison of patellar profiles is shown in Table 4, where the mean patellar profile parameters were higher in the female group, and the overall profile measurements were statistically significant. This illustrates that the size of the patella in females is smaller in both two and three dimensions.

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**Table 4.**
Patellar profile.

| | Male (45) | | Female (41) | | P value |
|---|---|---|---|---|---|
| | Mean ± SD | range | Mean ± SD | Range | |
| CCL (cm) | 4.33 ± 0.29 | 3.31 – 5.09 | 3.77 ± 0.28 | 3.11 – 4.49 | <0.001* |
| TL (cm) | 4.38 ± 0.30 | 3.5 – 4.96 | 3.80 ± 0.34 | 3.01 – 4.43 | <0.001* |
| APL (cm) | 1.82 ± 0.27 | 1.25 – 2.37 | 1.61 ± 0.19 | 1.24 – 1.96 | <0.001* |
| C (cm) | 13.57 ± 0.89 | 10.86 – 16.05 | 11.85 ± 0.88 | 9.92 – 13.78 | <0.001* |
| A ($cm^2$) | 13.31 ± 1.44 | 10.62 – 17.26 | 12.02 ± 1.53 | 7.88 – 14.62 | <0.001* |

**Note:** * Analysis using Independent T-Test.

## 4. Discussion

The literature has highlighted differences in trochlear measurements between males and females. Choi's study found significant differences in sulcus angle based on both gender and age among subjects under 19 years old. However, neither the sulcus angle nor femoral depth showed significant differences in the 16-18 age group.[6] This change can be attributed to the growth of the distal femoral physis, which typically completes by age 18. Thus, this study suggests that age has no effect since the distal femur ossification process has been completed. Hsu et al. conducted research using CT scan data to reconstruct 3D models with variations in rotation angles for axial sections. They found that the average sulcus angle in females is larger than in males at rotation angles ranging from -30° to -10°, with a statistically significant difference only at -10°. Specifically, the average sulcus angle in female subjects is about 5.2° larger compared to males.[7] The rotation angle for axial cross-sections in routine MRI examinations varies depending on the operator, which may make the results less representative of actual size.

Mwakikunga et al. found no significant difference in the average sulcus angle between men and women.[8] Similarly, Nietosvaara found no significant gender-related differences in mean sulcus angles in a study of 100 knees from 25 boys and 25 girls.[9] Furthermore, Murshed et al. reported no differences in sulcus angle between males and females or between right and left sides.[10] The results of this study align with those findings.

Several factors, including condylar height and condylar width, influence facet asymmetry. The interaction between anterior condylar height and trochlear width has a significant impact on the structure of the trochlear groove and, consequently, on patellar stability.[7] Individuals exhibit considerable variation in the anatomy of the anterior condyle; while there is no difference in the height of the medial and lateral condyles, differences exist in their ratio aspects.[11] Hsu et al. also found significant differences in condylar width, with measurements ranging from 20° to 0° for the lateral condyle and from 10° to 20° for the medial condyle. In females, the width ratio of the lateral femoral trochlea is approximately 7.9% greater than in males. These findings suggest that the height and wider angle indicate a shallower anterior trochlea in the mediolateral direction in women compared to men.

The results of this study did not show facets of asymmetry less than 40%, lateral trochlear inclination less than 11°, or trochlear depth less than 3 mm. This is consistent with findings from other studies.[12, 13] Arora et al. conducted a study on 30 patients with clinically demonstrated patellar instability, which revealed a 70% decrease in trochlear depth, a facet asymmetry of less than 40%, and a 33.3% decrease in lateral trochlear inclination.[12]

Measuring patellar height can be broadly classified into two groups: direct and indirect methods, depending on whether the femur or tibia is used as the reference point for the patella. Among all methods, the Insall-Salvati Index (ISI) is the most popular, accurate, and simple. A lateral radiograph of the knee can yield this index without requiring a specific angle of flexion.[14] Other methods for measuring patellar height include the Caton-Deschamps Index (CDI), Modified Insall-Salvati Index (MISI), Blackburne-Peel Index (BPI), and Patellotrochlear Index (PI).[15]

In this study, the Insall-Salvati Index (ISI) was found to be statistically significant, with higher values in women than in men. These results are consistent with the findings of other studies.[16, 17] In

his study, Hong et al. noted that patella alta is present when the ratio exceeds 1.2, and patella baja when the ratio is less than 0.64 in the Korean population.

Previous studies in Indonesia reported different results, with several showing no significant differences in patellar height values between males and females using the ISI method ($p = 0.500$), MISI ($p = 0.095$), CDI ($p = 25.47$), and BPI ($p = 0.661$). These studies reported normal Insall-Salvati Index values within the range of 0.78 to 1.26, recommending an Insall-Salvati ratio >1.32 for patella alta and <0.72 for patella baja.[15, 18] Hoang et al. also obtained similar results in their study on the Vietnamese population.[19]

In contrast, a study by Althani et al. on the Insall-Salvati ratio in Middle Eastern countries found an average ratio of $1.20 \pm 0.17$, with men having a higher ratio ($1.22 \pm 0.12$) compared to women ($1.18 \pm 0.017$).[20] The study also recommended abnormal patellar position measurements of 1.54 for patella alta and 0.86 for patella baja. A South Indian study reported an average Insall-Salvati Index score of 1.34, with the male group scoring 1.41 and the female group scoring 1.28.[21] Although conducted within an Asian population, these reference values are on the higher end of the spectrum, with males showing a larger ratio. This contradicts findings from other studies. Factors such as lifestyle habits, including frequent squatting, sitting, and kneeling, are thought to contribute to the increased length of the patellar ligaments, influencing these results. The values of lateral patellar tilt and the bisect offset index represent the position of the patella in relation to the axial plane. In his research, Stefanik et al. found that the Insall-Salvati Index and lateral trochlear inclination are predictors related to both variables.[22]

Choi et al. observed a significant difference in TT-TG distance between males and females (men: $8.6 \pm 3.8$ mm, women: $7.2 \pm 4$ mm).[6] This contrasts with the findings of this study and others, where no significant difference in TT-TG distance by gender was observed.[18, 23] In a study conducted by Hingelbaum et al. in Germany with 200 samples of normal knees, the TT-TG distance in men was $7.5 \pm 3.7$ mm and in women $7.6 \pm 3.1$ mm.[23]

In the study by Rhatomy et al. conducted in Indonesia, the TT-TG value was measured with an average of $13.76 \pm 5.86$ mm (range: 4.9 - 41 mm), while this study reported an overall average of $14.015 \pm 6.042$ mm (range: 4.45 - 32.8 mm). In their study, Dejour et al. found that 56% of patients with a TT-TG > 20 mm had an increased risk of patellar instability, compared to 3-6.5% of those with normal knees. Seitlinger et al. reported an average TT-TG of $11.892 \pm 4.668$ mm in normal knees and $18.926 \pm 5.158$ mm in patients with a history of patellar dislocation.[24] 13 samples (15.1%) in this study still had TT-TG values greater than 20 mm. Notably, 13 samples (15.1%) in this study still had TT-TG values greater than 20 mm. The TT-PCL (Tibial Tuberosity-Posterior Cruciate Ligament) distance is another parameter used to evaluate the lateralization of the tibial tuberosity. Seitlinger et al. found that the average TT-PCL in normal patients was $18.425 \pm 3.346$ mm, while in patients with a history of dislocation, it was $21.88 \pm 4.295$ mm. The normal value for TT-PCL is recommended to be < 24 mm.[24] In this study, four samples (4.65%) had TT-PCL values > 24 mm, all of which were in the male group. Unlike the findings of Boutris et al., which identified a TT-PCL value > 21 mm as a pathological condition.[25] this study identified seven samples with TT-PCL values exceeding this threshold, all of which were also in the male group.

In the Japanese population, Ikuta et al. reported an average TT-PCL of 20.6 mm (range: 19.7-21.4 mm) in the normal group and 21.2 mm (range: 20.0-22.4 mm) in the group with a history of recurrent patellar dislocation.[26] Comparisons between male and female groups regarding the lateralization of the tibial tuberosity, as measured by PT-PCL and TT-PCL, are still limited. According to research by Marquez et al., TT-PGL and PT-PCL exhibit significantly less variability compared to the measurement of TT-TG, regardless of knee position.[26, 27]

This study compared patellar sizes between men and women. Significant differences were found in craniocaudal length (CCL), transverse length (TL), anteroposterior length (APL), circumference (C), and patellar area (A), with men showing higher mean scores than women in all measurements ($p < 0.001$). This indicates a marked difference in bone dimensions between the sexes in both two-dimensional and three-dimensional assessments. Other studies have also yielded similar results. Nguyen et al. measured transverse length (TL) and found significant differences based on gender and age. The

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average TL in males was 4.49 ± 0.25 cm, while in females it was 4.0 ± 0.31 cm. However, no significant difference was observed when compared to body mass index (BMI).[17]

Jain et al. conducted an anthropometric study of 200 patellae in the Indian population by measuring craniocaudal length (CCL), transverse length (TL), and anteroposterior length (APL). Significant differences were found according to sex ($p < 0.001$), with the male group showing the following measurements: CCL 4.378 ± 0.341 cm, TL 4.544 ± 0.34 cm, and APL 2.015 ± 0.205 cm. In contrast, the female group had measurements of CCL 3.891 ± 0.292 cm, TL 4.063 ± 0.326 cm, and APL 1.8 ± 0.173 cm. [28].

Patellofemoral instability may arise from inadequacies in the bone structures, ligaments, or neuromuscular elements, leading to misalignment or malltracking of the patella.[29] This instability primarily affects young women, with nearly half of dislocations occurring during physical exercise. Anatomical and morphological factors, such as trochlear dysplasia, patella alta, increased Q-angle, soft tissue flexibility, and muscle imbalances, are almost always present as predisposing factors for dislocation.[1] The most frequent dislocation takes place at knee flexion angles of up to 30 degrees, with external rotation of the tibial and quadriceps contractions, which are commonly observed in sports like football and in activities that involve rotational movements.[30] Another factor to consider is the greater difference in Q-angle between men and women. The normal Q-angle for men ranges from **10 to** 13 degrees**,** while for women, it ranges from 15 to 17 degrees.[31] In knees that exhibit a greater valgus alignment, the pull of the quadriceps muscles tends to direct the patella more toward the superolateral position.

This study assumed that the knee remains static in full extension, although patellar position parameters may vary with changes in knee flexion. Additionally, there are limitations related to variations in the sagittal, coronal, and axial planes that depend on the MRI operator. Increasing the number of samples, incorporating various ethnicities, and measuring in dynamic positions can provide a more representative evaluation of the population. Such research will be essential for developing more effective diagnostic and therapeutic strategies that address the unique anatomical and functional needs of different populations, ultimately improving patient outcomes in knee health and stability.

## 5. Conclusion

This study highlights significant anatomical differences between male and female knee structures, revealing that males generally possess deeper trochlear profiles, while females exhibit shallower profiles, smaller patellar dimensions, and a tendency for higher patellar positioning. The observed variations in trochlear depth, facet asymmetry, and patellar height may contribute to the higher prevalence of patellar instability among women. These results emphasize the necessity for tailored approaches in diagnosing and treating knee issues based on gender differences.

## Ethical Statement:

The Health and Research Ethics Committee of Dr. Soetomo General Academic Hospital has granted letter of exemption with the reference number 1324/LOE/301.4.2/VI/2023.



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