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Patellar Tilt Angle: Does it Truly Reflect Patellar Inclination?

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Abstract

Background: The patellar tilt angle (PTA), measured using the posterior bicondylar femoral line, reflects both patellar and femoral inclination. Femoral inclination relative to the horizontal represents knee internal torsion (KITA). When knee inclination exceeds patellar tilt, PTA may yield false-positiveresults. No prior studies have evaluated the incidence of false-positive PTA due to knee torsion.Differentiating these components is essential for accurate patellofemoral assessment.

Objective: To evaluate the incidence of false-positive PTA and the relative contributions of internal knee torsion and patellar inclination.

Methods: We analyzed 934 knees from 467 patients (mean age: 25.3 years; 79.4% women) with patellofemoral pain and instability, all showing a pathological PTA >10°. Subtracting KITA from PTA allowed us to assess each component's contribution.

Results: In 81.58% of cases, resultant patellar inclination was <10°, indicating a high false-positive rate. Knee torsion was the dominant factor in 77% of cases. Asymmetries were more pronounced in women.

Conclusion: PTA values based on the posterior bicondylar line often reflect internal knee torsion rather than patellar tilt. Accounting for torsion is essential to avoid misinterpreting patellar malalignment.

Abbreviations

PTA – Patellar Tilt Angle; PPTA – Pure Patellar Tilt Angle; KITA – Knee Internal Torsion Angle; PFI – Patellofemoral Instability; FPA – Foot Progression Angle; CT – Computed Tomography; ICC – Intraclass Correlation Coefficient; CV – Coefficient of Variation; GCP – Good Clinical Practice; CEI – Comité de Ética de Investigación (Research Ethics Committee); ANMAT – Administración Nacional de Medicamentos, Alimentos y Tecnología Médica; SD – Standard Deviation; FOV – Field of View; ANOVA – Analysis of Variance; Q-angle – Quadriceps Angle

Introduction

The patellar tilt angle (PTA) is a critical parameter in assessing patellofemoral maltracking and has long been recognized as a major contributor to patellofemoral instability (PFI) [1]. More recently, it has been suggested that an increased PTA may not only be associated with PFI but may also be a consequence of it [2-3]. Several etiologies have been implicated in elevated PTA, including quadriceps dysplasia, imbalances in vastus lateralis and vastus medialis oblique activation, patellar tendon-lateral femoralcondyle friction syndrome, and, classically, excessive lateral patellar retinacular tension [4-8]. More recently, emerging evidence has established a strong association between PTA and increased femoral anteversion, as reported by multiple studies [9-11]. These findings underscore the multifactorial nature of PTA abnormalities and their relationship with patellofemoral biomechanics.

The most widely used PTA measurement method, as described by Powers and Josserand-Dejour, integrates concepts from the techniques of Sasaki and Fulkerson [12-15]. This method relies on superimposed axial CT slices to measure the angle formed by the intersection of the patella's maximum width and the posterior bicondylar femoral line. However, since PTA reflects the inclination of both the patella and the femur, distinguishing the relative contributions of each is crucial for accurate diagnosis and treatment planning. True patellar tilt typically indicates the need for lateral retinacular lengthening or medial soft tissue reconstruction, whereas torsional derangement necessitates consideration of derotational osteotomy.

Although the posterior bicondylar femoral line serves as a reliable reference for femoral inclination, it also reflects knee internal torsion in relation to gait progression. The knee internal torsion angle (KITA), as described by Manilov et al., is measured using tomographic analysis in a gait-simulated position.

This angle is determined by the intersection of the posterior femoral line and a horizontal reference line parallel to the floor [16,17]. KITA represents the internal torsion of the entire knee, influenced by femoral anteversion, external tibial torsion, and foot progression angle [18,19]. Importantly, KITA is distinct from femoral anteversion, which specifically describes femoral torsion about its longitudinal axis.

From a biomechanical perspective, proper treatment algorithm development requires prioritizing knee alignment in relation to the body's line of advancement before addressing the patella-trochlear relationship. This ensures a physiologically sound approach, considering that forces affecting the patellofemoral joint act predominantly in anterior-posterior directions. Therefore, alterations in KITA result in significant changes in joint pressures.

Grelsamer et al. previously cautioned that internal femoral rotation could result in false-positive P values, potentially leading to misdiagnoses and inappropriate interventions [20]. This clinical observation highlights the importance of differentiating between patellar inclination and knee torsional components, as they stem from distinct pathophysiological mechanisms and require different therapeutic strategies. Despite its clinical significance, limited research has investigated the relative contributions of patellar inclination and knee torsion to PTA measurements. Furthermore, to date, no studies have quantified the incidence of false-positive PTA cases, defined as a PTA <10° after accounting for torsional influence.

Thus, the primary objectives of this study are first to evaluate the relative contributions of patellar inclination and knee internal torsion to PTA when using the posterior bicondylar femoral line as a reference and second to determine the incidence of false-positive PTA cases caused by KITA Our hypothesis is that PTA measurements based on the posterior bicondylar femoral line are more indicative of torsional abnormalities than true patellar inclination. To the best of our knowledge, this is the firststudy to investigate the incidence of false-positive PTA due to knee internal torsion and the first to analyze the relative preponderance of true patellar tilt versus torsional influence.

Materials and Methods

Participants: Participants provided written informed consent for their participation in the study. The study adhered to Good Clinical Practice (GCP) and the ethical standards set forth by the Declaration of Helsinki (1964) and national regulations under the Argentine Republic's Constitution (1994), ensuring patient rights were protected in accordance with Disposition 5330/97 of ANMAT. The study was approved by the ethics committee (CEI) of the Universidad Católica de Cuyo, San Juan, Argentina.

Between 2017 and 2024, CT scans of 934 knees from 467 patients were performed in our department. The sample included 96 men (192 knees, 20.56%) and 371 women (742 knees, 79.44%). Following the criteria described by Grelsamer et al., a pathological patellar tilt angle (PTA) was defined as a value greater than 10° [5]. All included patients presented patellofemoral symptoms, such as pain and/or instability, and had closed physis. Patients with pain and instability were not differentiated, as the purpose of the study was solely to analyze the incidence of false-positive values when measuring PTA, using the posterior bicondylar femoral line as a reference. Exclusion criteria included open physis, prior knee surgeries, rheumatoid arthritis, and tricompartmental knee arthritis.

Informed consent was obtained for all CT scans, and the study was approved by the ethics committee of our institution. All imaging studies followed the same protocol, based on the technique described previously [16], to ensure a comprehensive and functional assessment of torsional profiles.

CT Scan Protocol

Patients were positioned according to their foot progression angle (FPA), which was obtained by asking them to walk on a paper platform with their feet coated in 70% alcohol to leave an imprint (Figure 3). During the scan, patients lay in the supine position with their feet secured using Velcro straps over the pre-measured FPA footprint to prevent positional changes. Images were acquired with the knees fully extended (0° flexion) and the quadriceps relaxed. A General Electric MultiSlice Brightspeed Elite CT scanner (16 slices, software version 17BW11.2_SP1-1-1_HP_S_P16_G_HLT, China, 2011) was used, with 1.3 mm slices, 120 kV, 49 mA, a 512 x 512 matrix size, and a 43 x 43 cm FOV.

Measurement of Variable

This protocol evaluates intrinsic and extrinsic factors that affect the patellofemoral joint in a functional position that simulates gait, allowing surgeons to analyze the complete torsional profile. The measured variables include: acetabular version, femoral anteversion, external tibial torsion, femorotibial rotation, lateral trochlear inclination, patellar tilt angle, sulcus--tuberosity distance, tibial tubercle torsion, sulcus trochlear angle, and foot progression angle. For the purpose of this study, we used the following variables: PTA, KITA, and PPTA.

Patellar Tilt Angle (PTA)

The PTA measurement was taken with the knee fully extended (0° flexion). The angle was calculated by overlapping two axial images: one showing the patella's longest cross-sectional diameter and the posterior femoral bicondylar line (Figure 1). Figure 1A illustrates patient positioning in the CT scanner.

The foot progression angle (FPA) footprint was marked using 70% alcohol before drying. In Figure 1B, the patient was positioned on the scanner with their feet aligned to their FPA footprint, replicating the knee's functional torsional position during gait. PTA was measured by intersecting two lines: one aligned with the patella's longest diameter and the other connecting the posterior edges of the femoral condyles (Figure 1C). Figure 1D shows an example of a false positive, where an increased PTA results from femoral torsion rather than patellar inclination.

Knee Internal Torsion Angle (KITA)

The KITA was measured by determining the intersection of the posterior bicondylar femoral line and a horizontal line parallel to the floor, which is perpendicular to an imaginary line representing bod progression during gait. For accurate positioning, the patient’s feet were secured using Velcro straps placed over their own foot progression angle footprint.

This method ensured that the torsional alignment of the knee was measured under conditions replicating natural gait mechanics, as shown in Figure 2. A positive KITA (convergent strabismus) is defined when the angle opens laterally, while a negative KITA (divergent strabismus) occurs when the angle opens medially.

Pure Patellar Tilt Angle (PPTA)

In order to evaluate which factor has a greater influence on the PTA value, we subtract KITA from PTA. If the resulting value is greater than 50% of PTA, we consider that true patellar inclination is preponderant over KITA. Conversely, if the resulting value is less than 50% of PTA, we consider that KITA is preponderant over true patellar inclination. The resulting value represents true patellar inclination relative to a horizontal line parallel to the floor. We have named this value the Pure Patellar Tilt Angle (PPTA), as we consider it to be independent of underlying torsion. Since this is a retrospective study involving multiple knees, we need to develop the following formula using the available previously measured data: PPTA=PTA−KITA.

A positive PPTA indicates inclination toward the lateral side of the knee, while a negative PPTA indicates inclination toward the medial side. Pathological PPTA was defined as a value greater than 10°. A "true positive PTA" was recorded when PPTA remained >10° after subtracting KITA from PTA, reflecting pathological patellar tilt. A "false positive PTA" was recorded when PPTA was <10°, indicating normal patellar tilt after accounting for torsional influences. Calculation of the Pure Patellar Tilt Angle (PPTA) is illustrated in Figure 3. The PPTA was determined using the formula: PPTA = PTA− KITA. In this example, using the Cobb method for graphical demonstration, the Patellar Tilt Angle (PTA) was measured as 24°, and the Knee Internal Torsion Angle (KITA) was measured as 30°, resulting in a PPTA of -6°. The negative PPTA indicates that the angle is open laterally. This example highlights how a PTA of 24° could be classified as a false positive for pathological patellar tilt because the resulting PPTA is less than 10°, emphasizing the importance of accounting for knee internal torsion in the evaluation of patellar tilt.

Observer Variability and Validation of KITA

All measurements were conducted by a single experienced co-author in diagnostic imaging. KITA measurement variability (intra- and inter-observer) was validated by three imaging specialists, each performing three measurements on 30 participants at one-week intervals. Reliability, reflecting both correlation and agreement, was assessed using the Intraclass Correlation Coefficient (ICC) for test- retest, intrarater, and interrater analyses (Figure 4).

Statistical analysis was performed with GraphPad Prism 10 (USA). To examine intra- and inter-group variability in KITA measurements for left and right knees across three weeks, mean and standard deviation were calculated for each knee, observer, and time point. A two-way ANOVA assessed the effects of knee side (left vs. right) and time (Week 1, 2, 3) on KITA, accounting for repeated measures.

Tukey's post-hoc test identified significant differences when main effects or interactions were observed. Intra-observer consistency was evaluated via the coefficient of variation (CV), expressed as the standard deviation divided by the mean of weekly measurements for each knee and observer. Inter-observer reliability was assessed using ICC (two-way random-effects model), with values interpreted as poor(<0.5), moderate (0.5–0.75), good (0.75–0.9), or excellent (>0.9). Significance was set at $p<0.05$.

Percentages of knees with PTA >10° and PPTA >10° (true positive PTA) and PTA >10° with PPTA <10° (false positive PTA) were calculated (Figure 5). KITA and PPTA values were compared to determine the dominant factor contributing to PTA. If KITA > PPTA, knee internal torsion was dominant; if PPTA > KITA, patellar tilt was dominant (Figure 6). A chi-square test compared right vs. left knee preponderance in men and women to identify potential sex-specific asymmetries in knee mechanics (Figure 7).

Results

Interrater Reliability Analysis for KITA

A two-way ANOVA was performed to evaluate the effects of rater, week, and their interaction on knee angle measurements. The analysis revealed no significant main effect of rater on angle values, $F(2,531)=0.57$, $p=0.563$, indicating consistent measurements across the three raters. Similarly, there was no significant main effect of week, $F(2, 531)=0.08$, $p=0.921$, suggesting stability of measurements across the three consecutive weeks. Furthermore, the interaction effect between rater and week was not significant, $F(4, 531)=0.04$,

p=0.997, demonstrating that the combination of rater and week did not influence the knee angle measurements. These findings suggest that the measurements were reliable and unaffected by either evaluator or temporal factors (Figure 4).

The inter-observer agreement (reliability) was assessed using the Intraclass Correlation Coefficient (ICC). The Right Knee ICC Value obtained was 0.898: This value indicates a very high level of agreement among observers for the right knee measurements. Generally, an ICC above 0.75 is considered high, while a value above 0.90 is excellent. Thus, 0.898 suggests good reliability for these measurements. 95% Confidence Interval: Ranges from 0.841 to 0.942, further supporting the high agreement and suggesting minimal variability in reliability among observers. The extremely low p<0.001 indicates that the observed ICC is statistically significant. This confirms that the agreement among observers is not due to chance.

The Left Knee ICC Value obtained was 0.951. This value is even higher than that of the right knee, indicating excellent reliability and agreement among observers for these measurements. 95% Confidence Interval: Ranges from 0.921 to 0.973, indicating very high and consistent reliability. This p-value (p <0.001) is also extremely low, confirming that the observed reliability is statistically significant and not due to chance.

Both ICC values demonstrate a high level of agreement among observers for the measurements of both knees, with the left knee showing slightly superior agreement compared to the right knee. These results suggest that the measurements for both knees are consistent and reliable, with minimal variability attributable to differences between observers. For clinical practice or research, these findings indicate that the measurements performed by these observers are valid and consistent for studying both knees.

False Positive PTA driven by torsional factors rather than true patellar inclinationas depicted in Figure 5A, we further analyzed the percentage of true and false-positive PTA cases and examined the relative contributions of KITA and PPTA to the overall PTA measurement. The proportion of cases with PPTA < 10° was approximately 82.66% for right knees and approximately 80.51% for left knees. The combined analysis of both knees revealed that 81.58% of cases presented a PPTA < 10°, while 17.13% had a PPTA > 10°, and 1.29% exhibited a PPTA exactly equal to 10°. These findings indicate that the majority of cases fall below the 10° threshold, with a smaller proportionexceeding this value and a minimal percentage precisely at the threshold. The higher proportion of PPTA < 10° suggests that knee internal torsion has a predominant influence over patellar tilt as the primary contributor to the overall patellar tilt angle (PTA). These findings highlight the importance of distinguishing between true patellar tilt and torsional influences when assessing patellofemoral maltracking. Failure to account for knee torsional components may lead to misinterpretation of PTA severity and its clinical implications.

Knee internal torsion as the dominant factor influencing PTA

The analysis of preponderance for both knees combined revealed that knee internal torsion was the dominant factor influencing PTA in 76.98% of cases, while patellar tilt preponderance accounted for 21.41% (Figure 5B). Additionally, 1.61% of cases showed an equal contribution of PPTA and KITA (PPTA = KITA). When examined separately, the right knee presented a knee internal torsion preponderance of 80.73% and patellar tilt preponderance of 19.27%, while the left knee showed 75.80%and 24.20%, respectively. The mean PTA across all cases was 14.78° (SD: 8.73°, range: 0° to 35°), while the mean KITA was 13.98° (SD: 7.29°, range: 0° to 35°). The pure patellar tilt angle (PPTA) averaged 0.81° (SD: 10.56°, range: -25° to 33°). These results indicate a consistent predominance of knee internal torsion over patellar tilt in determining PTA across both knees, with slight variation between sides and a minor percentage of equal contribution cases.

Sex-Specific Preponderance Patterns Influencing PTA Measurements

As depicted in Figure 6, we analyzed sex-specific differences in knee mechanics. Among 371 women (742 knees), knee internal torsion was the predominant factor influencing PTA, with a combined prevalence of 82.21%. Patellar tilt accounted for 17.79%. Internal torsion was more frequent in the right knee (84.91%) than the left (79.51%), suggesting rotational forces play a larger role in patellar alignment than patellar tilt in women. Among 96 men (192 knees), internal torsion predominated in 63.02% of cases, with patellar tilt observed in 36.98%. Internal torsion was slightly more common in the right knee (64.58%) than the left (61.46%), but the difference between torsion and tilt was less pronounced compared to women. The chi-square test revealed a significant difference in reponderance patterns between sexes ($\chi^2 = 8.32$, $p = 0.0039$). A z-test comparing torsion prevalence showed a highly significant difference ($z = -5.75$, $p = 9.13 \times 10^{-9}$), confirming that internal torsion is significantly more prevalent in women than men.

We conducted a comparative analysis of knee preponderance between men and women, revealing significant sex-specific differences (Figure 7). Women showed a higher frequency of right knee internal torsion (350 vs. 120, $\chi^2 = 20.78$, $p < 0.0001$) and left knee internal torsion (340 vs. 110, $\chi^2 = 18.45$, $p < 0.0001$) compared to men. Right knee patellar tilt also differed significantly (50 vs. 30, $\chi^2 = 6.34$, $p = 0.012$), while left knee patellar tilt showed no significant variation.

Discussion

The most important finding of this study is that PTA is highly influenced by knee internal torsion. The hypothesis was confirmed, as using the femoral bicondylar line as a reference when measuring PTA conceals an underlying torsional factor and provides more information about knee torsion than patellar tilt itself. A high proportion of cases initially identified with pathological PTA were revealed to be false positives upon correcting for internal knee torsion, with 73% of the cases showing this effect. To the best of our knowledge, this is the first study to describe the relationship between PTA and knee internaltorsion.

Several publications have identified torsional disorders as a cause of failure and poor clinical outcomes in patellofemoral surgery, emphasizing the importance of recognizing and correcting torsional disorders early [21-26]. However, the extent to which knee internal torsion (KITA) influences PTA remainsunderexplored.

These findings suggest that using the posterior femoral bicondylar line as a reference to measure PTA may lead to clinical misinterpretation. For example, an increased PTA could lead surgeons to consider lateral patellar retinaculum retraction or quadriceps dysplasia, when in reality, "the problem is in the floor, not in the ceiling [2,5]. In most cases, increased PTA may instead reflect underlying knee internaltorsion, becoming apparent when the patient is positioned in a functional gait simulation. The high incidence of false positives observed in this study may be attributed to our CT protocol, which positions patients according to their foot progression angle (FPA) footprint. This functional positioning provides a more accurate representation of internal knee torsion compared to traditional imaging protocols.

Our findings align with the work of Teitge et al., who described the pathophysiology of inwardly pointing knees, emphasizing that femoral anteversion, lateral tibial torsion, and foot progression angle imbalances create lateral vector forces leading to patellofemoral instability and pain [17,18]. However, correcting the knee internal torsion rather than addressing patellar tilt alone may be essential to restore joint balance in a high proportion of patients. Our functional CT protocol uniquely measures knee internal torsion relative to a gait-simulating axis, emphasizing the need for alignment with body progression to reduce shear joint forces and increase contact surface.

Lin et al. further highlighted the effects of femoral and tibial rotation on patellar alignment, concluding that patellar malalignment cannot be evaluated independently of limb alignment [27]. Similarly, Grelsamer et al. associated PTA values exceeding 10° with patellar tilt that could not be corrected through physical examination, suggesting lateral retinacular tightness [5]. Our study expands on these findings, emphasizing that knee internal torsion is a highly preponderant factor in increased PTA values,surpassing the influence of patellar tilt alone.

Recent studies by Kang et al. demonstrated a strong correlation between increased PTA and femoral anteversion in patients with recurrent patellar dislocation, recommending femoral derotational osteotomy in cases with anteversion above 25° [9]. Tian et al. reported similar reductions in PTA following femoral osteotomy, while Kaiser et al. confirmed increased PTA with femoral anteversion augmentation in a biomechanical cadaver study [10-11]. Our results differ, as they focus on the roader influence of knee internal torsion rather than femoral anteversion alone, particularly in a functional position where FPA and tibial external torsion influences torsional effects. It is important to differentiate knee internal torsion from femoral anteversion, as the latter represents the angle formed between the two extremities of the femur (neck and condyles), while knee torsion reflects the torsion of the entire knee within the lower limb axis. Knee torsion can be increased by femoral anteversion and external tibial torsion, often in combination with a typically normal foot progression angle. The PPTA measurement method, which uses the patellar cross-sectional axis and a horizontal reference line, offers a more direct evaluation of true patellar tilt without the masking effect of torsional components. This approach aligns with Grelsamer et al. 's methodology but differs in functional positioning, as their study fixed the patient's feet together, while our protocol aligns with the FPA footprint. Grelsamer reported a mean PPTA of 2° ± 2° in controls and 12° ± 6° in pathological knees, with a cutoff value of 5° for excessive patellar tilt (20). Our findings support the need for such functional imaging to differentiate between patellar inclination and torsional influences accurately.

The observed difference in knee preponderance between men and women, particularly the higher prevalence of knee internal torsion in women, could be attributed to several anatomical, biomechanical,and physiological factors. Women generally have a wider pelvis compared to men, resulting in a larger Q-angle, defined as the angle between the femur and tibia. This increased Q-angle can contribute to greater internal knee rotation, predisposing women to knee internal torsion [28-30]. Additionally, women often exhibit greater femoral anteversion, characterized by the forward rotation of the femoral neck, which further influences the alignment of the knee joint and may promote increased internal torsion [31-33]. Women tend to have greater ligament laxity due to hormonal influences [34,35]. Thiscan result in reduced joint stability and altered knee alignment, favoring internal torsion. Lower stiffnessin the ligaments and tendons may also contribute to greater knee internal rotation during weight-bearing activities. Women often have weaker hamstring activation and altered quadriceps dominance compared to men, which can affect knee joint stability and alignment [36,37]. Differences in proprioception and neuromuscular control may also impact how the knee handles mechanical stress, with a tendency toward increased internal torsion [38,39].

The chi-square analysis revealed significant knee asymmetry in men and women, with stronger effects in women. While internal torsion dominated in both sexes, women showed higher deviations, particularly in left knee patellar tilt and right knee internal torsion. These findings underscore the importance of knee internal torsion as an additional factor in women, alongside their larger Q-angle, increased femoral anteversion, ligament laxity, and altered neuromuscular control. This combination likely amplifies biomechanical asymmetries, increasing injury risk and functional limitations, highlighting the need for sex-specific assessments.

This retrospective study has some limitations, including the absence of a control group due to ethical concerns regarding radiation exposure in asymptomatic individuals. Additionally, the functional CT protocol, based on FPA positioning, may have influenced the detection of internal torsion. Further research, including MRI studies, is necessary to establish pathological PPTA thresholds and validate these findings in other populations.

Despite these limitations, this study provides groundbreaking evidence of the significant role of knee internal torsion in PTA values. It is the first to identify a high rate of false-positive PTA results caused by torsion and to analyze the relative contributions of torsion and patellar tilt. The introduction of PPTA as a novel tool for isolating patellar inclination enhances diagnostic accuracy. With its large sample size, the study offers robust conclusions, emphasizing the clinical relevance of knee internal torsion in both diagnosis and treatment planning. Proper differentiation between true patellar tilt and torsional influences is essential for accurate diagnosis and surgical decision-making.

Further research should investigate whether these asymmetries are linked to increased injury susceptibility or functional limitations.

Conclusion

This study demonstrates a high incidence of false-positive PTA results caused by knee internal torsion when measurement methods use the posterior femoral line as a reference. The findings emphasize the substantial preponderance of torsional factors over true patellar inclination in PTA values. This study holds clinical relevance by highlighting the need for orthopedic surgeons to consider knee internal torsion rather than solely attributing changes in PTA to true patellar inclination.

Figure 1: Methodology for PTA measurement and an example of a false positive. (A) The patient's foot progression angle (FPA) footprint was marked after moistening the feet with 70% alcohol. (B) The patient was positioned on the CT scanner with their feet aligned to the FPA footprint to replicate the

functional torsional position of the knee during gait. (C) The PTA was calculated by overlapping two axial views: one showing the longest diameter of the patella and another depicting the bicondylar line. (D) An example of a false positive PTA is presented, where an elevated PTA value is attributed to femoral torsion rather than true patellar inclination.

Figure 2: KITA measurement technique with Manilov´s tomographic method. Knee internal torsion with the patient positioned to simulate gait over their footprint, aligned with the foot progression angle. KITA is obtained from the intersection of posterior bicondylar femoral line and horizontal line parallel to the floor which is perpendicular to an imaginary line of body progression during gait.

Figure 3: Calculation of the Pure Patellar Angle (PPTA). In this example, using Cobb method for graphical purpose, (A) PTA 24° minus (B) KITA -30° = (C) PPTA -6°. It is a negative PPTA, meaning that angle is open laterally. In this example PTA is false positive because resulting PPTA is minor than 10°.

Figure 4: Knee Angle Measurements Across Raters and Weeks (A-C) Knee angle measurements for the right knee across 30 subjects evaluated by Rater 1 (A), Rater 2 (B), and Rater 3 (C) during three consecutive weeks. (D-F) Knee angle measurements for the left knee across 30 subjects evaluated by Rater 1 (D), Rater 2 (E), and Rater 3 (F) during the same period. A two-way ANOVA was performed to evaluate the effects of rater, week, and their interaction on knee angle measurements. The analysis revealed no significant main effect demonstrating that the combination of rater and week did not influence the knee angle measurements. These findings suggest that the measurements were reliable and unaffected by either evaluator or temporal factors.

Figure 5: Knee internal torsion as the dominant factor influencing PTA (A) Incidence of false positive patellar tilt angle due to knee internal torsion. The pie chart illustrates the distribution of cases based on PPTA values in the combined knee data. 81.58% of cases had PPTA < 10°, 17.13% exhibited PPTA > 10°, and 1.29% presented a PPTA exactly equal to 10°. The high proportion of cases with PPTA < 10° suggests that knee internal torsion plays a predominant role in patellar tilt angle measurements, contributing to potential false-positive findings. (B) Distribution of preponderance in combined knee data. The pie chart illustrates the relative contribution of knee internal torsion preponderance (76.98%), patellar tilt preponderance (21.41%), and cases wherePPTA equals KITA (1.61%) to the overall patellar tilt angle (PTA). Knee internal torsion was the dominant factor, with a minor proportion of cases showing balanced contributions between torsion and patellar tilt.

Figure 6: Black columns represent the prevalence of knee internal torsion and patella tilt in the male sample, consisting of 96 participants (192 knees). Knee internal torsion was the predominant factor influencing PTA measurements, observed in 63.02% of cases, while patella tilt accounted for 36.98% of cases. Gray columns depict the prevalence of these components in the female sample, comprising 371 participants (742 knees). Knee internal torsion was significantly more prevalent in females, with a combined prevalence of 82.21% across both knees, whereas patella tilt was observed in 17.79% of cases. These findings highlight a notable difference in the predominance of PTA components between male and female samples.

Figure 7: Comparison of knee preponderance patterns between men and women. The clustered bar chart displays observed frequencies for each category: Right Knee Internal Torsion, Right Knee Patellar Tilt, Left Knee Internal Torsion, and Left Knee Patellar Tilt. Bars for men (gray) and women (dark gray) are shown side by side for each category. Statistically significant differences between men and women are indicated with asterisks: $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Horizontal lines highlight the categories analyzed for statistical significance. The analysis demonstrates a higher frequency of internal torsion in women compared to men, emphasizing sex-specific differences in knee mechanics.

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