TUSYAD STArt
Sports Traumatology & Arthroscopy
DOI: 10.14744/start.2024.35086
Sports Traumatol Arthrosc 2025;2(2):55–63

Original Article

A Novel Radiographic Measurement to Quantify Tibial Tubercle Lateralization: Tibial Tubercle-Posterior Cruciate Ligament Angle

Engin Demirayak,[1] Ozkan Kose[2]

[1]Clinic of Orthopedics and Traumatology Yalvac State Hospital, Yalvac, Isparta, Türkiye
[2]Department of Orthopedics and Traumatology University of Health Sciences, Antalya Training and Research Hospital, Antalya, Türkiye

ABSTRACT

Objective: This study aimed to introduce a novel angular measurement—tibial tubercle–posterior cruciate ligament angle (TT–PCL angle)—to quantify tibial tubercle lateralization in patients with patellofemoral instability (PFI). Secondary objectives included assessing its reliability, diagnostic performance, and correlation with established linear measurements.

Materials and Methods: This retrospective case-control study included 43 patients with objective PFI and 100 controls. Two independent observers measured TT–PCL angle, TT–TG distance, TT–PCL distance, and their normalized variants on axial CT scans at two time points. Inter- and intraobserver reliability were assessed using intraclass correlation coefficients (ICCs). Correlations between measurements were analyzed, and diagnostic performance was evaluated using ROC curve analysis.

Results: All variables were significantly higher in the PFI group than in controls ($p < 0.001$). The TT–PCL angle demonstrated excellent intra- and interobserver reliability (ICC > 0.90). A cutoff value of >20.25° yielded 65.1% sensitivity and 85.0% specificity for detecting pathological lateralization. The angle strongly correlated with TT–PCL and normalized TT–PCL distances, but not with TT–TG measures in the PFI group.

Conclusion: The TT–PCL angle is a reliable and practical tool for assessing tibial tubercle lateralization. Unlike conventional measurements, it is based solely on tibial landmarks and is unaffected by knee size or femoral anatomy. Its strong diagnostic performance and reproducibility support its potential use in routine clinical practice.

Keywords: Computerized tomography, patellofemoral instability, tibial tubercle lateralization, TT-PCL distance, TT-TG distance.

Cite this article as:
Demirayak E, Kose O. A Novel Radiographic Measurement to Quantify Tibial Tubercle Lateralization: Tibial Tubercle-Posterior Cruciate Ligament Angle. Sports Traumatol Arthrosc 2025;2(2):55–63.

Address for correspondence:
Engin Demirayak.
Clinic of Orthopedics and Traumatology Yalvac State Hospital, Yalvac, Isparta, Türkiye
E-mail:
engin.demirayak@hotmail.com

Submitted: 06.07.2025
Accepted: 28.07.2025
Available Online: 18.08.2025

Sports Traumatology & Arthroscopy – Available online at www.stajournal.com

INTRODUCTION

Patellofemoral instability (PFI) commonly arises due to various underlying anatomical risk factors. Among the most significant of these are trochlear dysplasia, patella alta, lateralization of the tibial tubercle (TT), limb alignment abnormalities, increased Q angle, weakness of the vastus medialis muscle, and incompetence of the medial patellofemoral ligament (MPFL).[1–3] Although a detailed patient history and thorough physical examination are generally sufficient to diagnose PFI, imaging studies are essential to determine the most appropriate treatment strategy.[3] An important imaging parameter in this context is the degree of lateralization of the tibial tubercle, which helps guide the decision for distal realignment surgery in patients with objective PFI.[3,4] The tibial tubercle–trochlear groove (TT–TG) distance is the most widely used method for assessing TT lateralization. A TT–TG distance exceeding 20 mm is generally considered pathological.[2,5]

However, the TT–TG distance is influenced by rotational alignment and flexion of the knee, as the reference points are located on two separate bones—the tibia and the femur.[6–9] Moreover, in the presence of trochlear dysplasia, the deepest point of the trochlear groove is often medially displaced, which can artificially increase the TT–TG value.[10] Accurately identifying this deepest point can be particularly challenging in severe cases of trochlear dysplasia, thereby reducing the reliability of the measurement.[11,12] To address these limitations, Seitlinger et al. proposed the tibial tubercle–posterior cruciate ligament (TT–PCL) distance as an alternative measurement, as both landmarks are located on the tibia and, therefore, less affected by rotational variation.[13] Nevertheless, both TT–TG and TT–PCL measurements are influenced by individual knee dimensions.[14–16] To account for this, normalized indices have been developed by comparing these values with additional parameters that reflect knee size.[17,18]

Given these challenges, there is a clear need for a novel measurement technique that is unaffected by knee rotation or size and does not require supplementary measurements. We hypothesized that an angular measurement based solely on tibial landmarks may offer a more reliable solution, similar in concept to the TT–PCL distance. The primary aim of this study was to introduce a new radiographic measurement technique—the TT–PCL angle—to quantify tibial tubercle lateralization. The secondary aims were to assess the reliability of this method, evaluate its diagnostic performance, and analyze its correlation with existing measurement techniques.

MATERIALS AND METHODS

Patients and Study Design

This study was designed as a retrospective case-control study. All patients who underwent surgical treatment for objective patellofemoral instability (PFI) at the authors' institution were retrospectively reviewed between January 2014 and January 2019. Patients were excluded if they had a history of fractures around the knee joint, congenital or acquired deformities that significantly altered knee anatomy, or incomplete or inadequate medical records or computed tomography (CT) scans. The remaining patients comprised the case group.

The control group was randomly selected from individuals who presented to the emergency department with knee trauma and had undergone a knee CT scan. In addition to the exclusion criteria applied to the case group, control group patients were also excluded if they exhibited any radiographic signs of PFI, including trochlear dysplasia, patellar tilt greater than 20°, patella alta (Caton–Deschamps index > 1.2), TT–TG distance > 20 mm, TT–PCL distance > 24 mm, normalized TT–TG (nTT–TG) > 0.25, or normalized TT–PCL (nTT–PCL) > 0.31. These criteria ensured that the control group consisted exclusively of individuals without radiographic evidence of PFI, even in its subtle forms. The study followed the ethical standards of the Declaration of Helsinki and its later amendments. The institutional review board approved the study protocol (IRB approval number: 2019/088).

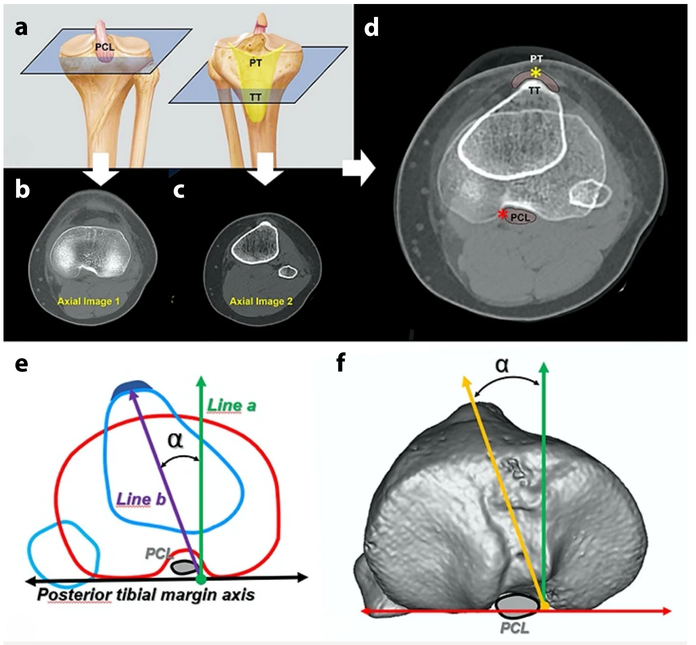


Figure 1. Measurement Technique for the Tibial Tubercle–Posterior Cruciate Ligament Angle (TT–PCL Angle). **(a)** Schematic representation of the axial CT planes used to identify the medial border of the posterior cruciate ligament (PCL) and the center of the patellar tendon (PT) insertion at the tibial tubercle (TT). **(b)** Axial CT image at the level of the PCL (Image 1). **(c)** Axial CT image at the level of the TT (Image 2). **(d)** Superimposed axial CT image showing the identified landmarks: the medial border of the PCL (red asterisk) and the center of the PT at the TT (yellow asterisk). **(e)** Schematic illustration of the TT–PCL angle (α), measured between Line a (perpendicular to the posterior tibial margin axis) and Line b (connecting the PCL and PT landmarks). **(f)** 3D CT reconstruction demonstrating the spatial orientation of the TT–PCL angle (α) using the same anatomical landmarks.

Description of the TT-PCLAngle

To measure the TT–PCL angle, two axial CT sections were utilized: one at the level of the proximal tibia just above the fibular head and the other at the level of the tibial tubercle where the patellar tendon attaches. These two images were superimposed using dedicated imaging software to allow precise alignment and measurement. The posterior tibial margin axis was first drawn as a reference line on the merged image. Next, the medial border of the posterior cruciate ligament (PCL) and the midpoint of the patellar tendon insertion were identified. From the medial border of the PCL, a perpendicular line was drawn to intersect the posterior tibial axis. A second line connected the patellar tendon's midpoint to the PCL's medial border. The angle formed between these two lines was defined as the TT–PCL angle (Fig. 1).

CT Protocol and Measurements

CT scans were obtained with patients in the supine position and the knee in full extension, using the same CT machine for all subjects (Philips Brilliance CT 64 Channel-DS, Koninklijke Philips Electronics N.V., Amsterdam, The Netherlands). Measurements were performed on digital CT images stored in the hospital's Picture Archiving and Communication System (PACS), using the Sectra IDS7 software (Version 18.2, Sectra AB, Linköping, Sweden) on a dedicated workstation.

Two independent observers performed all measurements twice, at two separate time points, with a minimum interval of four weeks between sessions. In addition to the TT–PCL angle, the following parameters were measured: TT–TG distance, normalized TT–TG (nTT–TG) distance, TT–PCL distance, normalized TT–PCL (nTT–PCL) distance, and the tibiofemoral knee rotation angle, each in accordance with previously described methods. To normalize distance measurements, the tibial maximal mediolateral axis (TMMA) was used as the reference parameter (Fig. 2).

Reliability analysis used the intraclass correlation coefficient (ICC) and corresponding 95% confidence intervals. ICC values were interpreted as follows: 0.81–1.00=excellent, 0.61–0.80=good, 0.41–0.60=moderate, 0.21–0.40=fair, and 0.00–0.20=poor.[19] Inter-observer and intra-observer reliability were rated as excellent or good for all measured variables; therefore, the average of the four measurements was used for the final analysis (Table 1).

Statistical Analysis

Statistical analysis was conducted using SPSS Statistics Base version 23 for Windows (IBM Corp., Armonk, NY, USA). Descriptive statistics were reported as frequencies and percentages (%) for categorical variables and mean±standard deviation (SD), median, and range for continuous variables. The normality of data distribution was assessed using the Shapiro–Wilk and

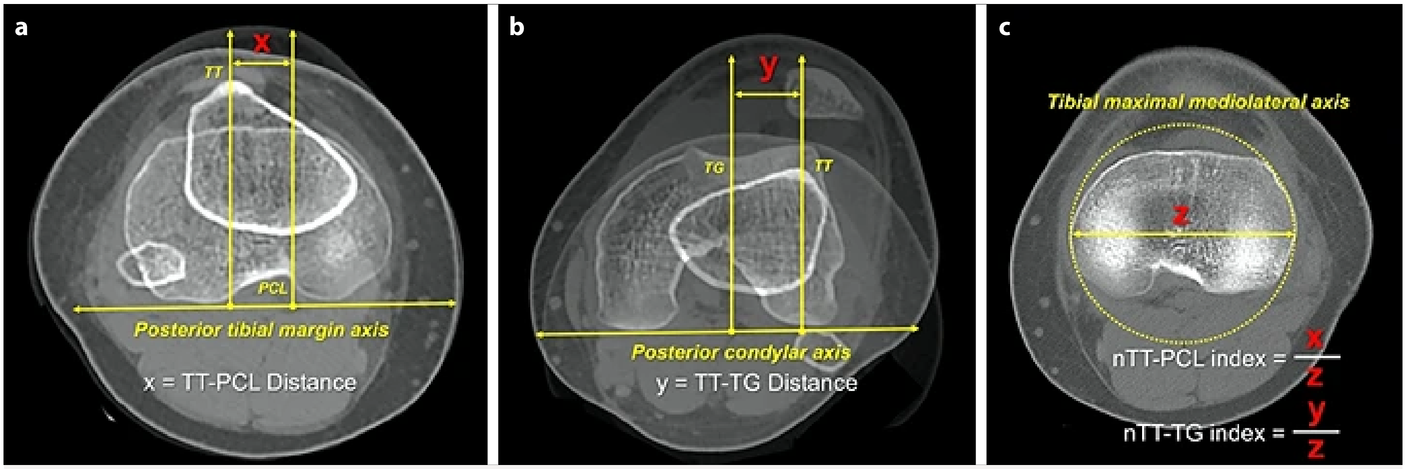


Figure 2. Measurement of Linear and Normalized Tibial Tubercle Lateralization Parameters. **(a)** Axial CT image showing the measurement of the tibial tubercle–posterior cruciate ligament (TT–PCL) distance (x), defined as the horizontal distance between the center of the tibial tubercle (TT) and the medial border of the posterior cruciate ligament (PCL), referenced to the posterior tibial margin axis. **(b)** Axial CT image illustrating the tibial tubercle–trochlear groove (TT–TG) distance (y), measured from the deepest point of the trochlear groove (TG) to the center of the TT, referenced to the posterior condylar axis. **(c)** An axial CT image at the tibial plateau level demonstrating the tibial maximal mediolateral axis (z) is used to normalize both TT–PCL and TT–TG distances. The normalized TT–PCL index is calculated as x/z, and the normalized TT–TG index as y/z.

Table 1. Results of reliability analysis

Variable	Reliability Analysis, ICC (95% CI)			
	Intra-observer Reliability		Inter-observer Reliability	
	A t1 vs. A t2	*B t1 vs. B t2*	*A t1 vs. B t1*	*A t2 vs. B t2*
TT-PCL Angle	0.995 (0.993-0.997)	0.975 (0.965-0.982)	0.888 (0.846-0.919)	0.875 (0.829-0.909)
TT-PCL Distance	0.996 (0.995-0.997)	0.968 (0.956-0.977)	0.876 (0.832-0.909)	0.881 (0.839-0.913)
n TT-PCL	0.995 (0.993-0.997)	0.963 (0.949-0.974)	0.858 (0.807-0.896)	0.860 (0.811-0.897)
TT-TG Distance	0.998 (0.997-0.999)	0.998 (0.997-0.998)	0.806 (0.580-0.896)	0.803 (0.584-0.892)
n TT-TG	0.998 (0.997-0.998)	0.998 (0.997-0.998)	0.791 (0.532-0.890)	0.788 (0.546-0.886)
TMMA	0.998 (0.997-0.999)	0.995 (0.993-0.996)	0.949 (0.928-0.964)	0.950 (0.930-0.964)

ICC: Interclass correlation coefficient; CI: Confidence interval; *t1*: First time; *t2*: Second time. A: Observer A, B: Observer B.

Kolmogorov–Smirnov tests. Comparisons of means between independent groups were performed using the student's t-test. Relationships between categorical variables were analyzed using Pearson's chi-square test. Pearson's correlation test evaluated the association between continuous measurement variables. The diagnostic performance of each variable was assessed using receiver operating characteristic (ROC) curve analysis. Sensitivity, specificity, cutoff values, and the area under the ROC curve (AUC) were calculated. The optimal cutoff value for each parameter was defined as the point that maximized sensitivity and specificity for group differentiation.

RESULTS

There were 43 patients (25 female, 18 male) with a mean age of 25.0±10.1 years (range, 13-54) in the case group, and 100 patients (50 female, 50 male) with a mean age of 25.3±7.6 years (range, 13-40) in the control group (p=0.323 for age, p=0.371 for gender). All measured variables, TT-PCL angle, TT-PCL distance, nTT-PCL, TT-TG distance, and nTT-TG in the control group, were significantly higher compared to the case group, except for the tibial maximal mediolateral axis (TMMA) (Fig. 3). Although the distance measurements were higher in men, the normalized distance and angle measurements were equal between genders in the case group (Table 2).

There was a strong positive correlation between the TT-PCL angle and other measurements in the control group, but no correlation was found between the TT-PCL angle and TT-TG distance and nTT-TG distance in the case group (Table 3). ROC curve analysis revealed that the best cutoff value for the TT-PCL angle to differentiate normal and pathological tibial tubercle lateralization was >20.25 degrees (sensitivity=65.12%, specificity=85.0%). ROC curve diagrams and AUCs are presented in Figure 4.

A posthoc power analysis was performed using mean values of the TT-PCL angle in both groups on G*Power (ver.3.1.9.7). The study's power was calculated at 100% using a two-tailed student t-test, the effect size (df:1.413), an alpha of .05, and 143 subjects (43 vs. 100, allocation ratio:2.31).

DISCUSSION

This study aimed to develop a novel and reliable measurement technique to quantify tibial tubercle (TT) lateralization that is not influenced by knee size or rotational alignment and does not require additional measurements or normalization calculations. The TT–PCL angle was introduced using the same anatomical reference points as the TT–PCL distance. Accordingly, strong correlations were observed between the TT–PCL angle and both the TT–PCL distance (r=0.876) and the normalized TT–PCL (nTT–PCL) distance (r=0.912). Importantly, TT–PCL angle values were comparable between male and female participants in the case and control groups despite inherent differences in knee dimensions. These results suggest that the TT–PCL angle is independent of overall knee size, offering a clear advantage over traditional linear measurements. Furthermore, the TT–PCL angle provides equivalent information regarding TT lateralization without additional reference-based normalization or complex calculations. Another notable advantage of the TT–PCL angle is its excellent interobserver and intraobserver reliability. Although its specificity was slightly lower (by 5%) compared to the nTT–PCL distance, its sensitivity remained equivalent. Based on these findings, the TT–PCL angle emerges as a valuable auxiliary parameter that can be reliably used as an alternative to TT–PCL and nTT–PCL distances in clinical and radiographic evaluation of TT lateralization.

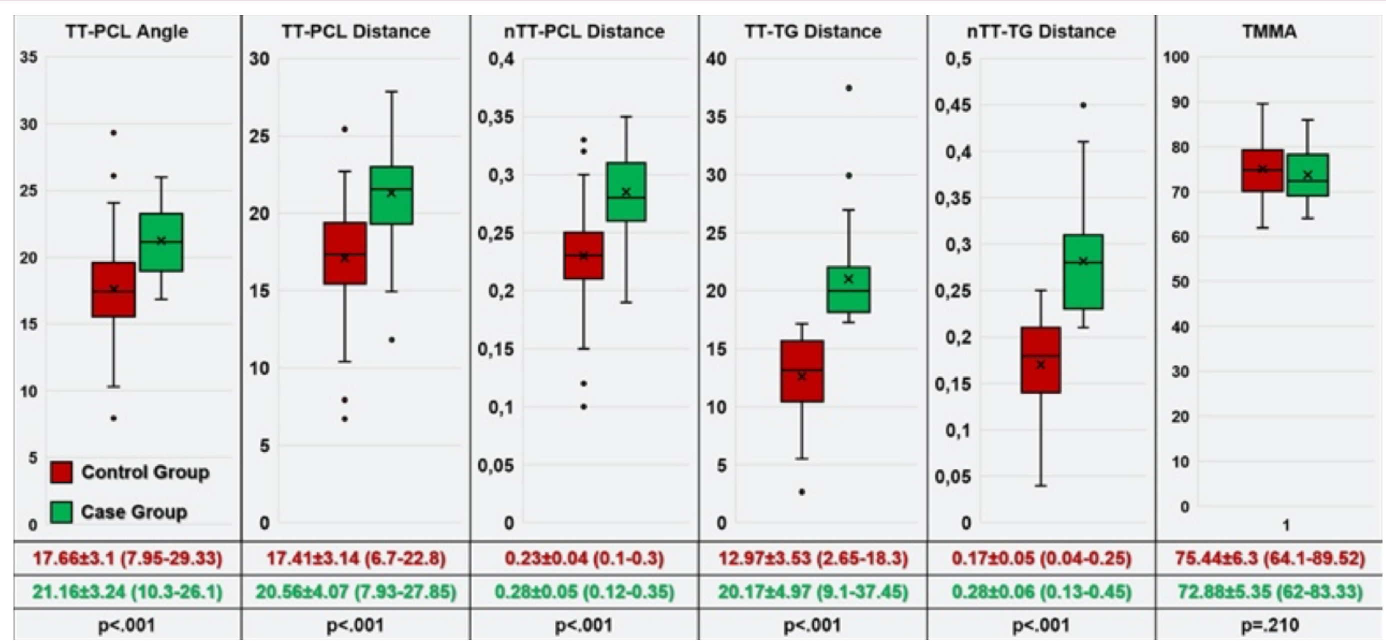


Figure 3. Comparison of Radiographic Measurements Between Case and Control Groups. Boxplots illustrate the distribution of six radiographic parameters used to assess tibial tubercle lateralization: TT–PCL angle, TT–PCL distance, normalized TT–PCL (nTT–PCL) distance, TT–TG distance, normalized TT–TG (nTT–TG) distance, and tibial maximal mediolateral axis (TMMA). Red boxes represent the control group, and green boxes represent the case group. The mean ± standard deviation and range are shown below the plots for each variable. Asterisks denote mean values, and horizontal lines indicate medians.

Seitlinger et al. introduced the tibial tubercle–posterior cruciate ligament (TT–PCL) distance as an alternative method to evaluate tibial tubercle lateralization in patients with patellar instability. The rationale behind their study was to overcome the limitations of the conventional tibial tubercle–trochlear groove (TT–TG) distance, which can be influenced by

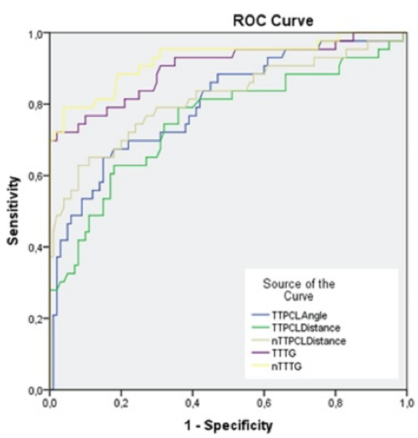
Table 2. Comparison of measurements in the patient and control groups according to gender

Control group	Female (n=50)	Male (n=50)	p
TT-PCL Angle	17.56±2.9(7.95-24.05)	17.77±3.32(11.38-29.33)	0.738
TT-PCL Distance	16.49±2.86(6.7-22.25)	18.32±3.17(11.08-22.8)	0.003
n TT-PCL	0.23±0.04(0.1-0.3)	0.23±0.04(0.15-0.28)	0.452
TT-TG Distance	12.38±3.28(2.65-17.78)	13.57±3.69(5.73-18.3)	0.092
n TT-TG	0.18±0.05(0.04-0.25)	0.17±0.05(0.07-0.24)	0.477
TMMA	70.59±3.75(64.1-79.98)	80.28±4.27(72.05-89.52)	<0.001
Case group	**Female (n=25)**	**Male (n=18)**	**p**
TT-PCL Angle	20.68±3.31(10.3-25.1)	21.82±3.1(17.08-26.1)	0.262
TT-PCL Distance	19.17±4.05(7.93-24.23)	22.5±3.31(16.08-27.85)	0.007
n TT-PCL	0.28±0.05(0.12-0.34)	0.29±0.04(0.22-0.35)	0.370
TT-TG Distance	18.55±3.89(9.1-25.35)	22.42±5.52(15.6-37.45)	0.010
n TT-TG	0.27±0.06(0.13-0.36)	0.29±0.07(0.21-0.45)	0.294
TMMA	69.31±3(62-76.03)	77.83±3.67(70.73-83.33)	<0.001

Table 3. Correlation of TT–PCL Angle with Other Measurements in the Case and Control Groups

Variables	Total		Control Group		Case Group	
	rho	p	rho	p	rho	p
TT-PCL Distance	0.876	<0.001	0.854	<0.001	0.862	<0.001
n TT-PCL	0.912	<0.001	0.869	<0.001	0.935	<0.001
TT-TG Distance	0.471	<0.001	0.299	0.003	0.211	0.173
n TT-TG	0.458	<0.001	0.238	0.017	0.203	0.191
TMMA	0.095	0.257	0.220	0.028	0.185	0.235

Pearson Correlation test.



	TT-PCL Angle	TT-PCL Distance	nTT-PCL Distance	TT-TG Distance	nTT-TG Distance
AUC (95% CI)	0.800 (0.725 - 0.862)	0.752 (0.673 - 0.820)	0.817 (0.743 - 0.876)	0.902 (0.840 - 0.945)	0.926 (0.870 -0.963)
Youden Index J (95% CI)	0.501 (0.337 - 0.624)	0.447 (0.2736 - 0.5672)	0.551 (0.3819 - 0.6707)	0.700 (0.5581 - 0.8140)	0.727 (0.564 - 0.814)
Cutoff (95% CI)	>20.25 (>19.67 - >22.70)	>20.05 (>18.32 - >21.72)	>0,2759 (>0,24 - >0,29)	>18.05 (>14.95 - >18.30)	>0.22 (>0.21 - >0.25)
Sensitivity	65.12%	62.79%	65.12%	72.09%	76.74%
Specificity	85.00%	82.00%	90.00%	98.00%	96.00%

Figure 4. Receiver Operating Characteristic (ROC) Curve Analysis and Diagnostic Performance of Tibial Tubercle Lateralization Parameters. The left panel displays ROC curves comparing the discriminative power of five radiographic measurements: TT–PCL angle (blue), TT–PCL distance (green), normalized TT–PCL (nTT–PCL) distance (orange), TT–TG distance (purple), and normalized TT–TG (nTT–TG) distance (yellow). The right panel summarizes the diagnostic performance for each parameter, including the area under the curve (AUC), Youden Index J, optimal cutoff values, sensitivity, and specificity with 95% confidence intervals.

knee rotation, flexion angle, and trochlear morphology.[13, 20] They emphasized that a pathological TT–TG distance (≥20 mm) does not always reflect true lateralization of the tibial tubercle, as it may also result from medialization of the trochlear groove, particularly in patients with trochlear dysplasia. Since TT–TG is measured between landmarks on different bones (femur and tibia), its accuracy may be compromised. In contrast, the TT–PCL distance relies solely on tibial landmarks, making it less susceptible to these confounding factors and potentially more reliable for surgical decision-making. Although the TT–PCL distance was a step forward in eliminating joint-crossing references, it still remained a size-dependent measure, limiting its use in children or individuals with smaller knees. Wagner et al., therefore, proposed a novel solution by normalizing the TT–PCL distance to the tibial head diameter (THD), resulting in the TT–PCL/THD index.[18] This index was independent of knee size and gender, providing a more reliable and universal tool for assessing true lateralization of the tibial tubercle. Their findings demonstrated that the TT–PCL/THD index more accurately distinguishes between normal and pathologic alignment in adults and children, making it a potentially superior alternative to existing methods in pediatric patellofemoral assessment. The angular measurement we propose offers a key advantage: it does not require a secondary measurement for normalization. Since angular assessments are inherently unaffected by joint size, the TT–PCL angle (TT–PCL-A) can be practically used to evaluate tibial tubercle lateralization in pediatric patients with small knees and adult patients with larger joint dimensions.

In addition to the angular measurement method described in our study, several alternative angular parameters have been reported in the literature to evaluate tibial tubercle (TT) torsion. Muneta et al. introduced the "TT rotation angle," defined between the posterior condylar line of the femur and the center of the patellar tendon at the level of the tibial tubercle. They reported significantly lower values in symptomatic female patients with patellofemoral pain compared to controls. Furthermore, they demonstrated a correlation between this angle and the degree of patellar tilt.[21] Similarly, Nagamine et al. showed that in knees with patellofemoral osteoarthritis (PF-OA), the TT becomes significantly more lateralized at 30° of flexion compared to extension, a finding attributed to inadequate internal rotation of the tibia during flexion. This dynamic malpositioning may increase the patellofemoral joint stress in PF-OA.[22] Hinckel et al. proposed a new parameter, the patellar tendon–trochlear groove (PT–TG) angle, demonstrating its excellent sensitivity and reproducibility in identifying patellar instability.[23] In another study, Chassaing et al. defined the "TT torsion angle" and found a value above 11.5° strongly associated with patellar instability, showing high specificity and sensitivity.[24]

However, most of these angular methods rely on reference points on different bones, such as the femur and tibia. They are therefore susceptible to variations in knee rotation and flexion angle. This can reduce the reliability and consistency of the measurements. In contrast, the TT–PCL angle described in our study is based solely on tibial landmarks, making it less influenced by knee positioning or femoral morphology. This methodological advantage may provide a more stable and practical assessment of TT torsion and lateralization. Moreover, our results demonstrated excellent intra- and interobserver reliability for the TT–PCL angle, supporting its applicability in routine clinical evaluation of patellofemoral alignment.

This study has several notable strengths. First, it introduces the TT–PCL angle as a novel, reproducible, and easily applicable radiographic measurement based solely on tibial landmarks, eliminating the influence of femoral morphology and knee positioning. Second, the study demonstrated excellent inter- and intraobserver reliability, supporting the clinical utility and reproducibility of this new angular parameter. Additionally, including a relatively large and gender-balanced control group strengthens the validity of the diagnostic performance analysis. Lastly, by comparing the TT–PCL angle with conventional and normalized linear measurements, the study comprehensively evaluates its clinical relevance in the context of existing diagnostic tools. However, certain limitations must be acknowledged. The study's retrospective design may introduce selection bias and restrict the control over imaging protocols, particularly regarding knee positioning during CT acquisition. Furthermore, although the medial border of the PCL was selected as a consistent anatomical landmark, it is a soft tissue structure whose apparent location may vary slightly with knee flexion. Additionally, while the exclusion criteria for the control group were stringent, the inclusion of individuals who underwent CT for non-PFI indications may still introduce unrecognized confounding factors. Lastly, the study lacks longitudinal follow-up to determine whether the TT–PCL angle correlates with clinical outcomes or treatment success.

CONCLUSION

The TT–PCL angle represents a novel, reliable, and practical radiographic parameter for assessing tibial tubercle lateralization in patients with patellofemoral instability. Unlike conventional linear measurements, this angular technique is based entirely on tibial landmarks, rendering it independent of knee size, rotational alignment, and the need for normalization. The TT–PCL angle demonstrated excellent intra- and interobserver reliability, strong correlation with established measurement methods, and favorable diagnostic performance with a cutoff value of >20.25°. Given its ease of application and reproducibility, the TT–PCL angle has the potential to serve as a valuable supplementary or alternative metric in the radiographic evaluation of patellofemoral alignment and surgical decision-making.

DECLARATIONS

Ethics Committee Approval: The Antalya Training and Research Hospital Scientific Research Ethics Committee granted approval for this study (date: 14.03.2019, number: 9/2).

Informed Consent: Not applicable.

Conflict of Interest: The authors declared no conflict of interest.

Financial Disclosure: The authors declared that they have no relevant or material financial interests that relate to the research described in this paper.

Funding Disclosure: No funding was received for this study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Use of AI for Writing Assistance: The authors declared that no AI-based tools were used in the preparation of this manuscript.

Author Contributions: Idea/Concept – ED, OK; Design – ED, OK; Control/Supervision – ED, OK; Data Collection and/or Processing – ED, OK; Analysis and/or Interpretation – ED. OK; Literature review – ED, OK; Writing – ED, OK; Critical Review – ED, OK; References and Fundings – ED, OK;Materials – ED, OK.

Peer-review: Externally peer-reviewed.

ABBREVIATIONS

AUC – Area Under the Curve

CT – Computed Tomography

ICC – Intraclass Correlation Coefficient

MPFL – Medial Patellofemoral Ligament

nTT–PCL – Normalized Tibial Tubercle–Posterior Cruciate Ligament Distance

nTT–TG – Normalized Tibial Tubercle–Trochlear Groove Distance

OA – Osteoarthritis

PCL – Posterior Cruciate Ligament

PFI – Patellofemoral Instability

PT – Patellar Tendon

PT–TG – Patellar Tendon–Trochlear Groove

ROC – Receiver Operating Characteristic

THD – Tibial Head Diameter

TMMA – Tibial Maximal Mediolateral Axis

TT – Tibial Tubercle

TT–PCL – Tibial Tubercle–Posterior Cruciate Ligament

TT–TG – Tibial Tubercle–Trochlear Groove

TT–PCL-A – Tibial Tubercle–Posterior Cruciate Ligament Angle

REFERENCES

1. Vellios EE, Trivellas M, Arshi A, Beck JJ. Recurrent Patellofemoral Instability in the Pediatric Patient: Management and Pitfalls. Curr Rev Musculoskelet Med 2020;13:58–68. [Crossref]
2. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 1994;2:19–26. [Crossref]
3. Weber AE, Nathani A, Dines JS, Allen AA, Shubin-Stein BE, Arendt EA, et al.. An algorithmic approach to the management of recurrent lateral patellar dislocation. J Bone Joint Surg Am2016;98:417–27. doi: 10.2106/JBJS.O.00354. Erratum in: J Bone Joint Surg Am 2016;98:e54. [Crossref]
4. Thompson P, Metcalfe AJ. Current concepts in the surgical management of patellar instability. Knee2019;26:1171–81. doi: 10.1016/j.knee.2019.11.007. [Crossref]
5. Dejour D, Le Coultre B. Osteotomies in Patello-Femoral Instabilities. Sports Med Arthrosc Rev2018;26:8–15. [Crossref]
6. Seitlinger G, Scheurecker G, Hogler R, Labey L, Innocenti B, Hofmann S. The position of the tibia tubercle in 0°–90° flexion: comparing patients with patella dislocation to healthy volunteers. Knee Surg Sports Traumatol Arthrosc 2014; 22:2396–400. [Crossref]
7. Suomalainen JS, Regalado G, Joukainen A, Kääriäinen T, Könönen M, Manninen H, Set al. Effects of knee flexion and extension on the tibial tuberosity-trochlear groove (TT-TG) distance in adolescents. J Exp Orthop 2018;5:31. [Crossref]
8. Izadpanah K, Weitzel E, Vicari M, Hennig J, Weigel M, Südkamp NP, et al.. Influence of knee flexion angle and weight bearing on the Tibial Tuberosity-Trochlear Groove (TTTG) distance for evaluation of patellofemoral alignment. Knee Surg Sports Traumatol Arthrosc 2014;22:2655–61. [Crossref]
9. Anley CM, Morris GV, Saithna A, James SL, Snow M. Defining the Role of the tibial tubercle-trochlear groove and tibial tubercle-posterior cruciate ligament distances in the work-up of patients with patellofemoral disorders. Am J Sports Med 2015;43:1348–53. [Crossref]
10. Tscholl PM, Antoniadis A, Dietrich TJ, Koch PP, Fucentese SF. The tibial-tubercle trochlear groove distance in patients with trochlear dysplasia: the influence of the proximally flat trochlea. Knee Surg Sports Traumatol Arthrosc 2016;24:2741–7. [Crossref]
11. Xu Z, Zhang H, Fu B, Mohamed SI, Zhang J, Zhou A. Tibial tubercle-roman arch distance: A New measurement of patellar dislocation and indication of tibial tubercle osteotomy.OrthopJSportsMed2020;8:2325967120914872. [Crossref]
12. Caplan N, Lees D, Newby M, Ewen A, Jackson R, St Clair Gibson A, et al. Is tibial tuberosity-trochlear groove distance an appropriate measure for the identification of knees with patellar instability? Knee Surg Sports Traumatol Arthrosc 2014 ;22:2377–81. [Crossref]
13. Seitlinger G, Scheurecker G, Hogler R, Labey L, Innocenti B, Hofmann S. Tibial tubercle-posterior cruciate ligament distance: A new measurement to define the position of the tibial tubercle in patients with patellar dislocation. Am J Sports Med 2012;40:1119–25. [Crossref]
14. Hingelbaum S, Best R, Huth J, Wagner D, Bauer G, Mauch F. The TT-TG Index: a new knee size adjusted measure method to determine the TT-TG distance. Knee Surg Sports Traumatol Arthrosc2014;22:2388–95. [Crossref]
15. Dickens AJ, Morrell NT, Doering A, Tandberg D, Treme G. Tibial tubercle-trochlear groove distance: defining normal in a pediatric population. J Bone Joint Surg Am. 2014;96:318–24. [Crossref]
16. Pennock AT, AlamM, BastromT. Variation in tibial tubercle-trochlear groove measurement as a function of age, sex, size, and patellar instability. Am J Sports Med 2014;42:389–93.
17. Cao P, Niu Y, Liu C, Wang X, Duan G, Mu Q, et al. Ratio of the tibial tuberosity-trochlear groove distance to the tibial maximal mediolateral axis: A more reliable and standardized way to measure the tibial tuberosity-trochlear groove distance. Knee 2018;25:59–65. [Crossref]

18. Wagner F, Maderbacher G, Matussek J, Holzapfel BM, Kammer B, Hubertus J, et al. A knee size-independent parameter for malalignment of the distal patellofemoral joint in children. Adv Orthop 2019;2019:3496936. [Crossref]
19. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175–91. [Crossref]
20. Seitlinger G, Scheurecker G, Högler R, Labey L, Innocenti B, Hofmann S. The position of the tibia tubercle in 0°-90° flexion: comparing patients with patella dislocation to healthy volunteers. Knee Surg Sports Traumatol Arthrosc 2014;22:2396–400. [Crossref]
21. Muneta T, Yamamoto H, Ishibashi T, Asahina S, Furuya K. Computerized tomographic analysis of tibial tubercle position in the painful female patellofemoral joint. Am J Sports Med 1994;22:67–71. [Crossref]
22. Nagamine R, Miura H, Inoue Y, Tanaka K, Urabe K, et al. Malposition of the tibial tubercle during flexion in knees with patellofemoral arthritis. Skeletal Radiol1997;26:597–601. [Crossref]
23. Hinckel BB, Gobbi RG, Kihara Filho EN, Demange MK, Pécora JR, Camanho GL. Patellar tendon-trochlear groove angle measurement: a new method for patellofemoral rotational analyses. Orthop J Sports Med 2015;3:2325967115601031. [Crossref]
24. Chassaing V, Zeitoun JM, Camara M, Blin JL, Marque S, Chancelier MD. Tibial tubercle torsion, a new factor of patellar instability. Orthop Traumatol Surg Res 2017;103:1173–8. [Crossref]