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Original Research

Overcoming Limitations in Tibial Tubercle–Trochlear Groove Distance Measurement

A Study of Its Reproducibility and Reliability in High-Grade Trochlear Dysplasia

Lucia Angelelli,* MD, David Mazy,*† MD, PhD, Nicolas Cance,* MD, Tomas Pineda,‡§ MD, Edoardo Giovannetti de Sanctis,‖ MD, and David H. Dejour,* MD
Investigation performed at Lyon Ortho Clinic, Lyon, France

Background: In cases of high-grade trochlear dysplasia, identifying the reference point of the trochlear groove can be challenging when measuring the tibial tubercle–trochlear groove (TT-TG) distance.

Purpose/Hypothesis: The purpose of this study is to evaluate the reliability of TT-TG measurements obtained at different trochlear reference levels. It was hypothesized that TT-TG measurements would remain feasible even in cases of high-grade trochlear dysplasia when alternative trochlear reference levels are used.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A retrospective analysis of magnetic resonance imaging scans from patients presenting with patellar instability between 2019 and 2023 was performed. For each patient, the TT-TG distance was measured at 3 levels on axial magnetic resonance imaging: high ($_{h}$TT-TG), middle ($_{m}$TT-TG), and low ($_{l}$TT-TG). The TT–posterior cruciate ligament (TT-PCL) distance was also measured. TT-TG values were compared across the 3 reference levels. Inter- and intraobserver reliability were assessed using the intraclass correlation coefficient (ICC).

Results: A total of 136 knees were included, of which 64% presented with high-grade trochlear dysplasia (37 Dejour type B and 50 type D). No statistically significant differences were observed between TT-TG measurements obtained at the 3 reference levels. The $_{h}$TT-TG could be measured in 115 of 136 knees. Among the 21 knees in which $_{h}$TT-TG could not be measured, 16 were associated with Dejour type D dysplasia, 1 with type C, 3 with type B, and 1 with type A dysplasia. The $_{l}$TT-TG was measurable in all patients. Interobserver ICC values were good and excellent for $_{l}$TT-TG, $_{m}$TT-TG, and $_{h}$TT-TG (0.877, 0.929, and 0.892, respectively), and intraobserver ICC values were also excellent (0.976, 0.976, and 0.954, respectively). The interobserver reliability for TT-PCL was moderate (ICC, 0.606), whereas intraobserver reliability remained excellent (ICC, 0.925).

Conclusion: TT-TG measurements remained feasible and reproducible in this cohort of patients with patellar instability, including a high proportion of high-grade trochlear dysplasia, when a slightly more distal trochlear reference level was used. TT-PCL remains a potential alternative although its interobserver reliability was lower than that of TT-TG in the present study.

Keywords: tibial tubercle–trochlear groove distance; trochlear dysplasia; patellar instability; trochlea; magnetic resonance imaging

The etiology of objective patellar instability (OPI) is multifactorial.[6] Several anatomic structures influence patellar tracking.[1] Among these, trochlear dysplasia, increased tibial tubercle–trochlear groove (TT-TG) distance and patella alta are recognized anatomic risk factors for objective patellar instability.[10] The bony morphology associated with OPI is complex, and a range of measurements has been developed to differentiate normal anatomy from abnormalities.[6] Identification and measurement of these

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factors allow the development of therapeutic strategies aimed at targeted correction of these anomalies.[7]

According to the literature, there is strong evidence that an increased value of TT-TG is a risk factor for developing first-time and recurrent patellar dislocation.[4] The TT-TG distance is the radiological expression of the knee extensor mechanism alignment. TT-TG reflects the lateralization of the TT relative to the TG, or the medialization of the TG.[13] The increase in this value results in an elevation of the force vector that contributes to lateral dislocation the patella.[8] Historically, this measurement was systematically performed using computed tomography (CT) scan, and it was defined as the distance between the most anterior point of the TT and the deepest bony point of the TG, perpendicular to the tangent to the bony borders of the posterior condyles on axial CT images.[11]

Over the years, magnetic resonance imaging (MRI) has progressively replaced CT in the preoperative planning of this pathology due to its superior ability to provide detailed information regarding the status of soft tissue and cartilage.[20] This distinction is particularly important when assessing the shape of the trochlear cartilage, which does not always conform to the underlying bony anatomy.[5,17] Differences in TT-TG pathologic thresholds between CT and MRI can be explained by variations in anatomic reference points, including bony versus cartilaginous landmarks, as well as a more anatomically accurate identification of the patellar tendon insertion on the TT on MRI.[20] Additionally, variations in measurement protocols may contribute to these discrepancies. Knee positioning during imaging also plays an important role, as slight knee flexion tends to decrease the measured TT-TG value. Therefore, the degree of knee flexion during image acquisition is a critical parameter when interpreting TT-TG measurements.[19]

On MRI, the TT-TG is assessed between the deepest cartilaginous point of the TG on the first cranial axial section where the trochlear cartilage appears and the center of the patellar tendon insertion on the TT. In high-grade dysplasia with a completely flat or even convex trochlea, it is critical to get this measure according to the method described above.[15] For this reason, Seitlinger et al[16] proposed methods to overcome this problem by introducing the concept of TT–posterior cruciate ligament (TT-PCL) distance, which does not take trochlear reference into account.

The aim of this study was to evaluate the reliability of TT-TG measurements taken at different trochlear levels. The hypothesis was that TT-TG measurements remain feasible even in cases of high-grade trochlear dysplasia when alternative trochlear reference levels are used.

METHODS

The study protocol received approval from the ethics committee of Clinique de la Sauvergarde, Ramsay Santé, Lyon, France.

Study Design

A retrospective analysis of MRI images was conducted from patients presenting to our institution between the years 2019 and 2023 for patellar instability with $\geq$1 patellar dislocation, regardless of the mechanism of injury. All data were prospectively recorded in our institutional registry. Inclusion criteria were a history of OPI and the availability of a knee MRI suitable for TT-TG and TT-PCL measurements. Exclusion criteria included patients with patellofemoral osteoarthritis defined as Iwano grade $\geq$2, associated ligamentous injuries other than medial patellofemoral ligament injury, previous knee surgery performed for conditions other than patellar dislocation, or any prior surgical procedure that could have altered the anatomic landmarks required for TT-TG or TT-PCL measurement. No age cutoff was applied; however, patients with open physes were excluded.

Measurement

Sex, age, laterality, and trochlear dysplasia according to the Dejour Version 2 classification were recorded.[3] Radiographic measurements were performed on MRI scans. Image analysis was carried out independently by 2 orthopaedic surgeons (L.A. and D.M.). For the intraobserver correlation coefficient, observer 1 (L.A.) read the MRI results blindly on 2 separate occasions (with a 6-week interval). The type of dysplasia, according to the Dejour Version 2 classification, was defined by the senior author (D.H.D.).[3] The software used was Horos Version 3.3.6 (Horos Project). MRI scans were conducted using a 1.5-T MRI. T2-weighted MRI slices were employed. All MRI examinations were performed according to our institutional protocol for the evaluation of objective patellar instability, with the knee positioned at approximately 20° of flexion. This positioning

†Address correspondence to David Mazy, MD, Lyon Ortho Clinic, Orthopedic Surgery Department, Clinique de la Sauvegarde, 29 Avenue des Sources, 69009 Lyon, France (email: david.mazy27@gmail.com).
*Lyon Ortho Clinic, Orthopedic Surgery Department, Clinique de la Sauvegarde, Lyon, France.
‡Hospital del Trabajador, Facultad de Medicina, Universidad Andre's Bello, Santiago, Chile.
§Hospital el Carmen, Facultad de Medicina, Universidad Finis Terrae, Santiago, Chile.
||Institut Universitaire Locomoteur et du Sport, Chirurgie Orthopédique, Nice, France.
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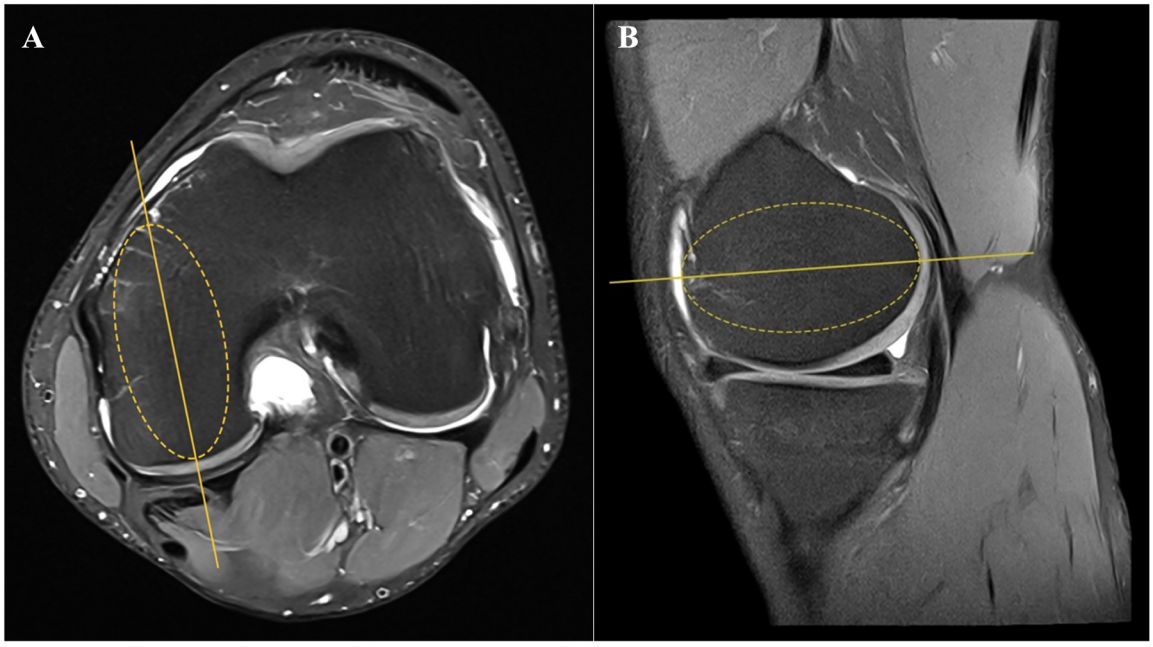


Figure 1. (A) Selection of medial condylar center on axial view. (B) Selection of medial condylar center on sagittal view.

allowed simultaneous assessment of patellar height parameters using the same imaging sequences.

TT-TG Assessment

The TT-TG was assessed through the following steps:

1. Axial image cut that intersected the center of the medial condyle was chosen (Figure 1A)
2. Sagittal image cut that intersected the center of the medial condyle was chosen (Figure 1B)
3. Tangent to the subchondral bone of the posterior femoral condyles was drawn (Figure 2A)
4. Perpendicular line to the deepest point of the cartilaginous trochlea (trochlear line) was drawn (Figure 2A)
5. Both lines were copied and pasted on the first axial cranial image where the patellar tendon attached to the TT, then a line parallel to the trochlear line passing through the center of the patellar tendon (patellar tendon line) was drawn (Figure 2B)
6. Distance between the trochlear line and the patellar tendon line represented the TT-TG distance (Figure 2B)

For each patient, TT-TG was measured at 3 different reference levels for the TG on the axial plane (Figure 3). These levels were defined based on reproducible anatomical landmarks, allowing a patient-specific approach rather than relying on fixed intervals:

- High TT-TG ($_{h}$TT-TG): the first cranial axial image presenting a complete cartilaginous trochlea
- Middle TT-TG ($_{m}$TT-GT): the axial image at midheight (with reference to the sagittal plane) of the medial condyle (Figures 1 and 2)
- Low TT-TG ($_{l}$TT-GT): the last image in cranial caudal direction where the trochlea remains continuous, just before separation into the 2 femoral condyles

In cases where the medial trochlear facet was poorly formed or absent, precluding reliable identification of the TG, the TT-TG measurement was considered not measurable.

TT-PCL Assessment

The TT-PCL was measured according to the methods described by Seitlinger et al[16] (Figure 4). This measure was used in this study as an independent reference from the TG landmark.

The TT-PCL was assessed through the following steps:

1. Dorsal condylar line of the tibia was defined on the slice just below the articular cartilage but superior to the proximal head of the fibula
2. Perpendicular line was drawn to the medial border of the PCL on the most inferior axial slice on which the PCL was still identified (PCL line: PCL-l)
3. Both lines were copied and pasted on the first axial cranial image where the patellar tendon attached to the TT, then a line was drawn parallel to the PCL line passing through the center of the patellar tendon (patellar tendon line: TT-l)
4. Distance between the PCL line and the patellar tendon line represented the TT-PCL distance

Statistical Analysis

Statistical analyses were performed using SPSS Statistics software (Version 29.0.2.0; IBM Corp). The normality of

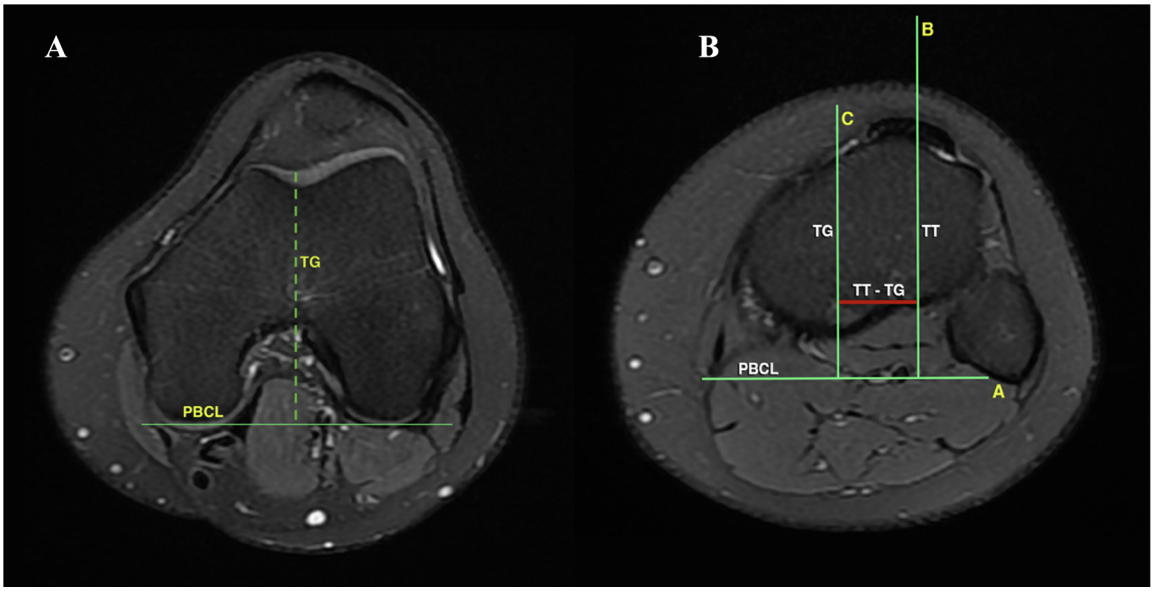


Figure 2. Tibial tuberosity–trochlear groove (TT-TG) distance measurement. (A) Solid tangent line to the subchondral bone of the posterior femoral condyles (PBCL) and perpendicular line (dotted line) crossing the deepest point of the TG. (B) Tangent line to posterior femoral condyles (PBCL or line A) and trochlear line (line C) copied and pasted on the first axial cranial image where the patellar tendon attaches to the anterior TT. The red line denotes the distance between the center of the patellar tendon and the center of the TG (line B). PBCL, posterior bicondylar line.

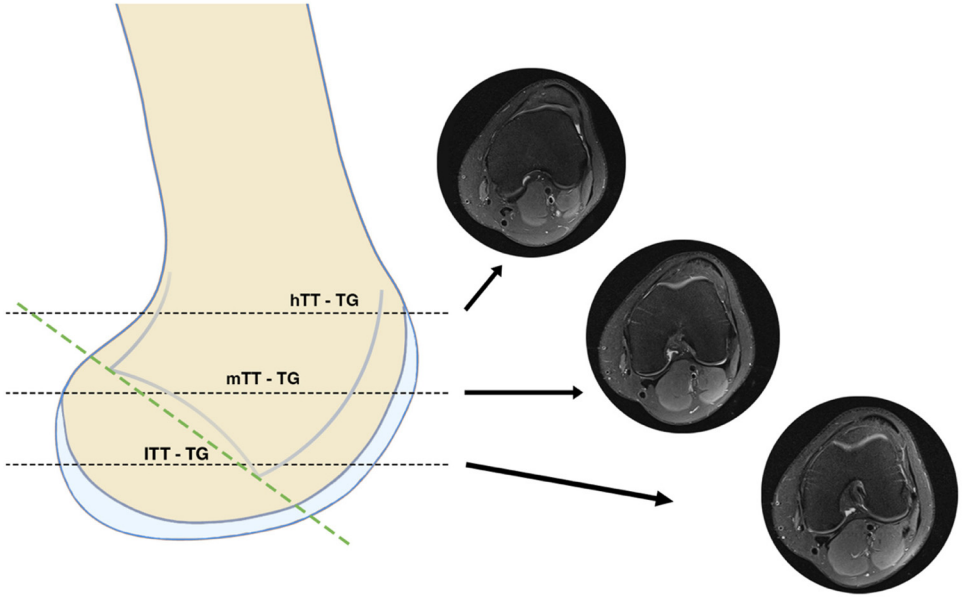


Figure 3. TT-TG measurements at 3 levels, using the axial plane. The Blumensaat line is represented by the green dotted line. h, high; l, low; m, middle; TT-TG, tibial tuberosity–trochlear groove distance.

continuous variables was assessed using the Shapiro-Wilk test. Normally distributed continuous variables, including age, TT-TG, and TT-PCL values, were reported as mean ± SD, whereas categorical variables were summarized using frequency distributions. Since TT-TG and TT-PCL values demonstrated normal distribution, parametric tests were used for statistical analyses. Because TT-TG measurements obtained at the different trochlear reference levels were paired within the same patients, comparisons between TT-TG values at the low, middle, and high reference levels were performed using paired Student *t* tests with Bonferroni correction for multiple comparisons. Since TT-TG and

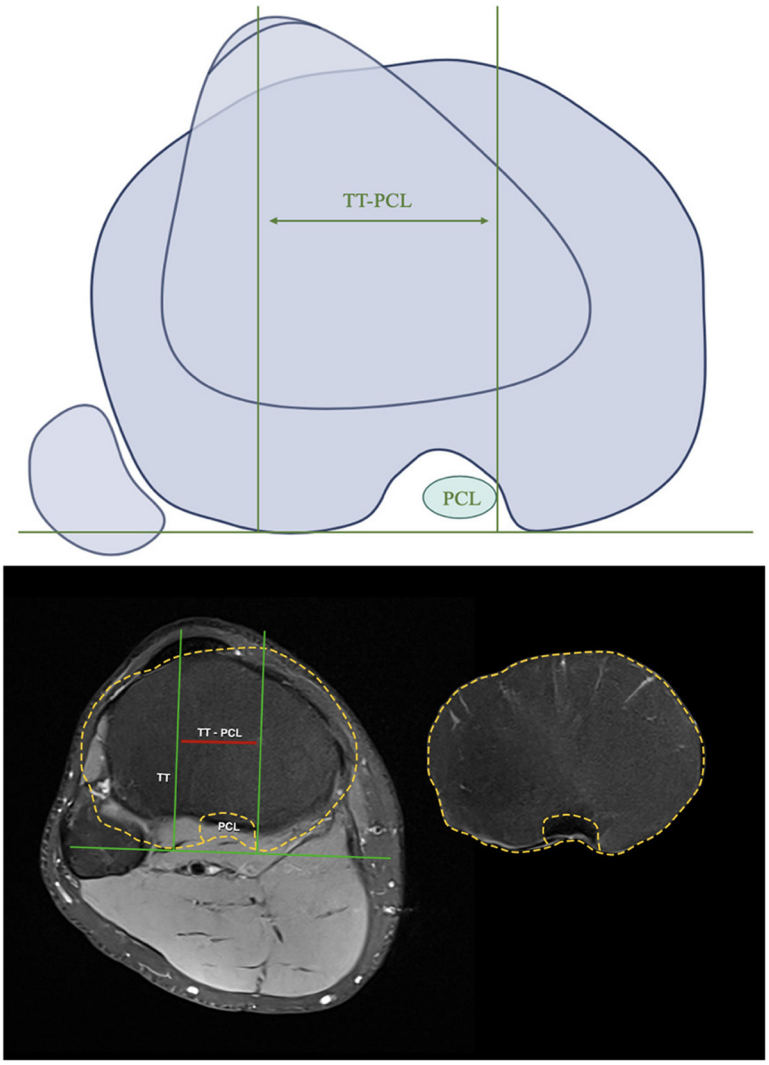


Figure 4. Tibial tubercle–posterior cruciate ligament distance (TT-PCL) measurement technique.

TT-PCL values demonstrated normal distribution, Pearson correlation coefficient was used to evaluate the correlation between $_{m}$TT-TG and TT-PCL measurements. Inter- and intraobserver reliability for TT-TG and TT-PCL measurements were assessed using the intraclass correlation coefficient (ICC). ICC values were interpreted according to Koo and Li,[12] with values <0.50 indicating poor reliability, 0.50-0.75 moderate reliability, >0.75-0.90 good reliability, and >0.90 excellent reliability. For interobserver reliability analysis, the 2 observers (L.A. and D.M.) were blinded to each other's measurements. A P value <.05 was considered statistically significant.

RESULTS

A total of 136 knee MRIs were analyzed from 54 men and 82 women with an age of 28.2 ± 9.7 years. The study flowchart is summarized in Figure 5. The demographic analysis of the population is described in Table 1. Of the total knees, 64% presented with high-grade trochlear dysplasia, including 37 knees classified as Dejour type B and 50 as type D.

As shown in Table 2, $_{l}$TT-TG, $_{m}$TT-TG and $_{h}$TT-TG were measurable, respectively, in 136, 134, and 115 knees. Among the 21 $_{h}$TT-TG missing measures, 16 were knees classified as dysplasia type D, three as dysplasia type B, one as dysplasia type A and one as dysplasia type C.

The inter- and intraobserver reliability was considered excellent or good for low, middle, and high TT-TG. The interobserver reliability for TT-PCL was only moderate (ICC, 0.606) (Table 3).

No statistically significant differences were found between TT-TG values measured at the 3 trochlear reference levels after Bonferroni correction ($P < .05$) (Table 4).

Pearson correlation analysis between $_{m}$TT-TG and TT-PCL demonstrated a moderate positive correlation (r = 0.552), as shown in Figure 6.

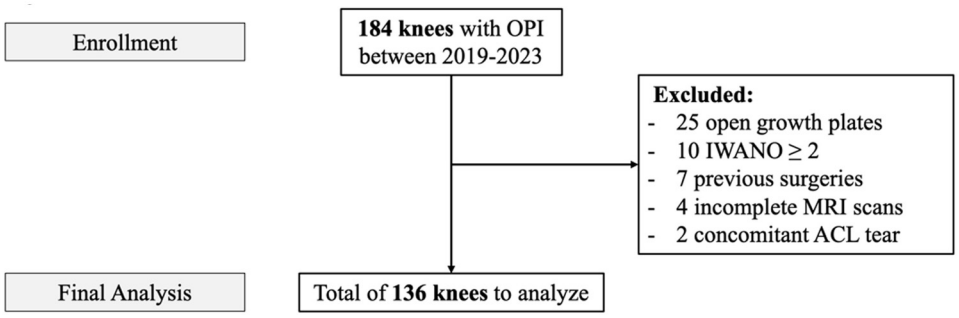


Figure 5. Flowchart of patients. ACL, anterior cruciate ligament; MRI, magnetic resonance imaging; OPI, objective patellar instability.

TABLE 1
Population Demographic Analysis (N = 136)

	n	%
Sex		
Female	82	60
Male	54	40
Laterality		
Right	61	45
Left	75	55
Dysplasia type		
A	39	29
B	37	27
C	10	7
D	50	37

TABLE 2
Mean TT-TG Distance and TT-PCL[a]

	n	%	Mean, mm	SD	Minimum-Maximum
TT-TG					
Low	136	100	15.0	5.1	2-34
Middle	134	98.5	15.1	5.3	2-35
High	115	84.6	14.9	5.5	3-36
TT-PCL	134	98.5	23.2	4.5	11-36

[a]TT-PCL, tibial tubercle–posterior cruciate ligament distance; TT-TG, tibial tuberosity–trochlear groove.

TABLE 3
Inter- and Intraobserver Reliability for TT-TG and TT-PCL Distance[a]

	Interobserver ICC (95% CI)	Intraobserver ICC (95% CI)
TT-TG		
Low	0.877 (0.791-0.934)	0.976 (0.960-0.990)
Middle	0.929 (0.882-0.963)	0.976 (0.960-0.990)
High	0.892 (0.820-0.941)	0.954 (0.921-0.973)
TT-PCL	0.606 (0.414-0.754)	0.925 (0.870-0.961)

[a]ICC, intraclass correlation coefficient; TT-PCL, tibial tubercle–posterior cruciate ligament; TT-TG, tibial tubercle–trochlear groove.

TABLE 4
Comparison of the Different (TT-TG) Distance[a]

	P
Low TT-TG vs middle TT-TG	.38
Low TT-TG vs high TT-TG	.90
Middle TT-TG vs high TT-TG	.68

[a]TT-TG, tibial tubercle–trochlear groove.

DISCUSSION

The most important finding of the present study was that no significant differences were observed between TT-TG measurements obtained at 3 different trochlear reference levels, supporting the validity of TT-TG assessment regardless of the severity of trochlear dysplasia. Among the 136 knees included in the study, TT-TG could be measured at the proximal trochlear reference level in only 115 cases. However, when the MRI slices were evaluated more distally, the $_{m}$TT-TG and $_{l}$TT-TG measurements became easier to identify and perform. At this level, the TG typically became deeper and more clearly defined, even in cases of high-grade dysplasia. Consequently, TT-TG measurements at the middle and distal trochlear levels were almost always obtainable. These findings indicate that even in the presence of high-grade trochlear dysplasia, a reliable and clinically meaningful TT-TG value can still be obtained by selecting a slightly more distal trochlear reference level.

TT-TG remains one of the most widely used parameters for evaluating patellofemoral instability. However, its reliability in cases of severe trochlear dysplasia has been questioned because identification of the TG may become difficult in flat or convex trochlea.[16] Seitlinger et al[16] proposed the TT-PCL distance as an alternative parameter intended to evaluate TT lateralization independently of trochlear morphology. In that study, among the subgroup

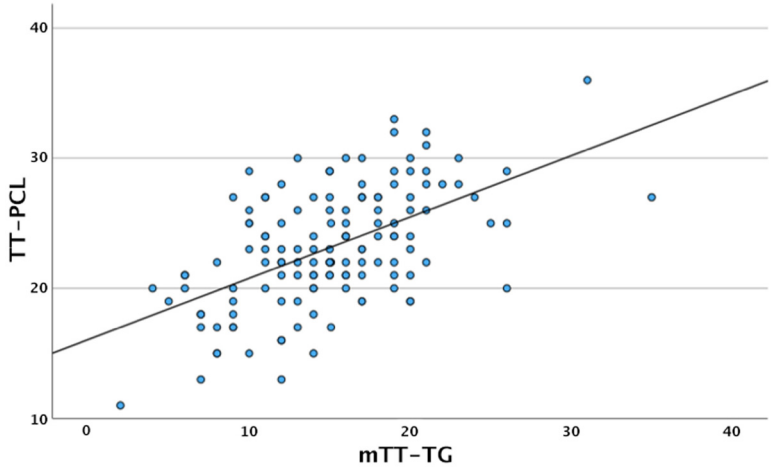


Figure 6. Correlation between $_{m}$TT-TG and TT-PCL investigated by Pearson *r* linear correlation analysis. $_{m}$TT-TG, middle tibial tubercle–trochlear groove distance; TT-PCL, tibial tubercle–posterior cruciate ligament distance.

of participants exhibiting a pathological TT-TG distance (≥20 mm measured on CT scan), 43% demonstrated a TT-PCL measurement within the normal range (<24 mm). From this, it can be deduced that the TT-PCL cannot supplant the TT-TG as an index for OPI risk because of its inferior sensitivity. Recent studies have demonstrated a lesser correlation between the true lateralization of the TT and the TT-PCL distance compared to the correlation with the TT-TG.[9] The increase in TT-TG may reflect either lateralization of the TT or medialization of the TG.[5] Proximal medialization of the TG has been described in trochlear dysplasia and tends to increase with dysplasia severity.[13] Despite these morphologic variations, they did not appear to induce sufficiently large changes in TT-TG values to be detected across the different trochlear reference levels assessed in the present study. These findings also suggest that pathological TT-TG threshold values may not require adjustment according to the selected trochlear reference level. Moreover, the TT-PCL does not offer specific guidance for clinical practice in the context of TT osteotomy surgical planning, in contrast to the TT-TG, which provides target values that can be used to inform surgical decisions.[18] This tendency supports the preference for using TT-TG over TT-PCL in our practice.

TT-TG offers a reliable and reproducible measure applicable to all types of dysplasia, with good and excellent intra- and interobserver ICC values. ICC interobserver for the TT-PCL measurement (ICC, 0.606) was found inferior compared with the $_{1}$TT-TG ICC interobserver (ICC, 0.877) and with that reported in the literature.[2,14,21] The moderate TT-PCL interobserver ICC could be attributed to a problem in determining which PCL reference cut to use. The TT-TG intraobserver was excellent at the 3 different levels, whereas the ICC intraobserver for TT-PCL was excellent, which emphasizes the subjectivity and less reproducibility of this measure. The moderate interobserver reliability observed for TT-PCL may also reflect the relative novelty of this measurement compared with TT-TG, which is more widely used and better standardized in clinical practice.

Limitations

We acknowledge several limitations of this study. First, it was a retrospective study and is therefore subject to the inherent limitations and potential biases associated with this design. Second, the reported measurements were based exclusively on MRI analysis and were not correlated with clinical outcomes or surgical findings nor compared with a control group without OPI. In addition, MRI acquisition was performed with the knee positioned at approximately 20° of flexion according to our institutional protocol, a positioning that may not be systematically reproducible across all institutions. Variations in MRI slice thickness may have influenced the exact positioning of the measurement levels. The observers had substantially greater experience with TT-TG measurements, which are routinely used in our clinical practice, than with TT-PCL measurements. This difference in familiarity may have influenced the reliability results and introduces a potential performance bias; therefore, comparisons between TT-TG and TT-PCL should be interpreted with caution. Also, the relatively small number of patients with Dejour type C dysplasia limits the ability to draw specific conclusions for this subgroup. Larger comparative studies, ideally conducted across multiple centers, would help strengthen the external validity of these findings.

CONCLUSION

TT-TG measurements remained feasible and reproducible in this cohort of patients with patellar instability, including a high proportion of high-grade trochlear dysplasia, when slightly more distal trochlear reference levels were used. These findings support the continued use of TT-TG

as a clinically useful parameter for evaluating patellofemoral instability, even when the proximal TG is difficult to identify. TT-PCL remains a potential alternative although its interobserver reliability was lower than that of TT-TG in the present study.

ORCID iDs

David Mazy https://orcid.org/0000-0003-2173-6167
Nicolas Cance https://orcid.org/0000-0002-9133-1598
Tomas Pineda https://orcid.org/0000-0002-9537-0658

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