Original Article

Tibial Tuberosity—Posterior Cruciate Ligament Distance

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Abstract

When trochlear dysplasia is present, it is difficult to measure the tibial tuberosity to trochlear groove (TT–TG) distance. A new measurement to assess tuberosity position was recently described by Seitlinger et al, which avoids the difficulty of identifying the TG as it references the posterior cruciate ligament (PCL). To evaluate the reproducibility of the Seitlinger et al findings, 42 knees in 41 patients with a documented history of recurrent patellar instability and 84 knees in patients with no history of patellar instability or patellofemoral symptoms were evaluated with magnetic resonance imaging. The TT–PCL distance was increased in the instability group (mean, 21.6 mm) compared with the control group (mean, 19.0 mm). The TT–PCL distance is an independent risk factor for patients with recurrent patellar instability. Its role in surgical planning remains to be determined.

Keywords
- ► TT–TG
- ► TT–PCL
- ► patellar instability
- ► patellar dislocation
- ► tibial tuberosity/ tubercle medialization

Patellar instability is a challenging condition for both the patient and the physician. The literature consistently supports nonoperative management of first time closed patellar dislocations without fracture or loose body. This may include physical therapy, taping, and bracing.[1–4] However, a subset of patients will develop recurrent patellar instability despite nonoperative treatment; 15 to 44% of first time dislocators recur and approximately 50% of patients have continued anterior knee pain and limited activity.[1,4,5] Surgery may be considered in patients when nonoperative treatment has failed. Preoperative planning includes identifying anatomic risk factors, such as knee rotation, trochlear dysplasia, and an increase in the lateral position of the patellar tendon attachment to the tibia. These may contribute to the instability and may be contemplated as an adjunctive surgical procedure. Traditionally, these risk factors have been determined with radiograph, computed tomography (CT), and/or magnetic resonance imaging (MRI). The tibial tuberosity to trochlear groove (TT–TG) distance was originally described by Goutallier et al[1] as a measurement on an axial radiograph and later adapted by Dejour et al[6] to CT (►**Fig. 1**). A measurement greater than 20 mm is considered a significant risk factor for patellar instability and may influence the consideration of TT medialization concomitant with medial patellofemoral ligament (MPFL) reconstruction.[1,2,6–16]

If a TT medialization osteotomy is contemplated in addition to MPFL reconstruction and other proximal surgery to optimize the treatment of a patient with recurrent patellar instability, accurate identification of the tuberosity position is essential for identifying the necessity and the amount of medialization. However, in a patient with trochlear dysplasia convex or flat morphology may be present and thus the measurement of the TT–TG distance is difficult (or impossible) as the true center of the TG cannot be accurately defined.[7,8,17,18] Nizić[19] described a method to estimate the center of the TG using the midpoint of the pericondylar distance on the posterior condylar line as a reference. This study showed no statistical difference between the described

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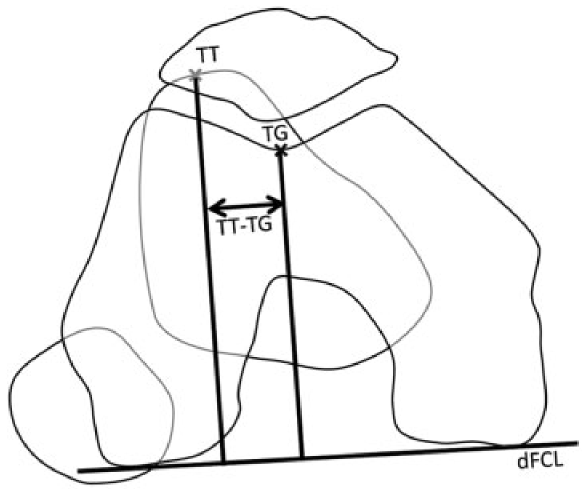

Fig. 1 Method for measuring TT–TG distance. The reference line is the dFCL (posterior). Lines perpendicular to the dFCL are drawn through the deepest point of the TG on an axial cut at the level of the "Roman arch" and through the midpoint of the TT at the level of the patellar tendon attachment. The distance between these lines is the TT–TG. dFCL, dorsal femoral condylar line; TT, tibial tuberosity; TG, trochlear groove; TT–TG, tibial tuberosity–trochlear groove distance. (Copyright © 2012 SAGE Publications. Reprinted with permission from Seitlinger et al.[7])

method and the traditional Dejour method, yet these were nondysplastic trochleas.[6] Obviously, the TT–TG combines in a single measurement the trochlear midpoint, local femur, and knee rotation as well as the lateral position of the TT (isolated or related to external tibial rotation). Thus, the measurement may increase as a result of abnormalities other than the isolated lateral position of the TT. To independently evaluate the lateral position of the TT, Seitlinger et al[7] described the TT–posterior cruciate ligament distance (TT–PCL), as the "mediolateral width between the tibial tubercle midpoint and the medial aspect of the PCL." The goal of the current study is to evaluate the findings of Seitlinger et al.[7]

Materials and Methods

After approval of institutional review board, MRI and patient data were retrospectively collected from June 2012 to March 2014. Patients were included if they had undergone an MRI. The patellar instability group was composed of patients with recurrent patellar instability. The OrthoIndy (Orthopaedic Indianapolis, private practice, Indianapolis, IN) patient registry was searched for diagnostic codes including patellar subluxation, and instability (718.36, 836.3) and a separate OrthoIndy procedural registry for tibial tubercle osteotomy and MPFL reconstruction. A total of 79 knees were identified, but 37 were excluded based on incomplete data, associated previous tibial tubercle osteotomy before obtaining the MRI, or a history of only a single patellar dislocation. The remaining 42 knees comprised the patellar instability group. A control group was composed of patients with no history of either anterior knee pain or patellar subluxation/dislocation. The control group was created by searching a patient registry (OrthoIndy) for the procedural codes representing partial meniscectomy or repair, anterior cruciate ligament (ACL) reconstruction, and removal of loose bodies (29,881/ 29,882; 29,888; 29,874, respectively). A total of 212 knees were initially identified; however, 128 knees were excluded because of incomplete data on MRI, previous surgery, or a history of patellofemoral pain. The remaining 84 knees comprised the control group.

The TT–TG, TT–PCL, and knee rotation measures were obtained as follows:

TT–TG: On the axial plane view, which demonstrated the intercondylar notch as a "Roman arch" the deepest point of the cartilaginous trochlea was marked as the TG, the posterior condylar line of the femur was drawn tangential to the posterior medial and lateral condyles. The TT point was marked as the midpoint of the patellar tendon insertion in the axial plane (most proximal cut of the TT) where it was completely inserted into the TT. Two perpendicular lines to the posterior condylar line of the femur were drawn from these two points. The distance between the two perpendicular lines is the TT–TG distance (►**Fig. 1**).

TT–PCL: A posterior condylar reference line of the tibia was drawn tangential to the posterior medial and lateral tibial plateaus (distal to the articular surface of the tibial plateau and proximal to the fibular head). The PCL point was defined as the medial border of the PCL in the most distal slice in which the ligament could still be clearly identified, which corresponds with the insertion of the ligament at the tibia. The TT point was the same for the TT–TG. Lines from the PCL and TT points were drawn perpendicular to the posterior condylar reference line of the tibia. The distance between the two perpendicular lines is the TT–PCL distance (►**Fig. 2**).

Knee rotation: defined as the rotation of the proximal tibia (posterior reference line) with respect to the distal femur (posterior reference line) (►**Fig. 3**).

Trochlear dysplasia was classified by Dejour et al (►**Fig. 4**).

The TT–TG and TT–PCL measures were completed, in all patients, by three examiners (radiologists specialized in musculoskeletal disorders, two with 9 years of experience, and one with 3 years of experience) independently and with no exchange of information during this part of the study. Measures were repeated after 2 weeks by examiners. Knee rotation was measured and trochlear dysplasia classified, in the patellar instability group, by one examiner (orthopedic surgeon specialized in knee surgery, with 4 years of experience, B.B.H.) once.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY) software. The intraclass correlation coefficient (ICC) for the three radiologists' TT–TG and TT–PCL measurements was analyzed. ICC values range from 0 to 1, where 1 indicates perfect agreement; a value higher than 0.75 indicates excellent agreement. The mean and standard deviation (SD) of TT–TG, TT–PCL, and knee rotation were calculated. An unpaired *t*-test compared the control and patellar instability groups with respect to the

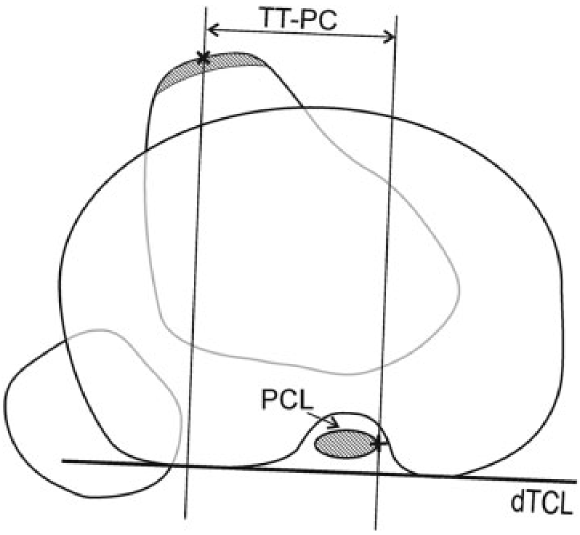

Fig. 2 Method for measuring TT–PCL distance. The reference line is the dTCL (posterior). Lines perpendicular to the dTCL are drawn through the medial margin of the PCL on an axial cut 1 cm distal to the tibial plateau and through the midpoint of the TT at the level of the patellar tendon attachment. The distance between these lines is the TT–PCL. dTCL, dorsal tibial condylar line; PCL, posterior cruciate ligament; TT–PCL, tibial tuberosity–posterior cruciate ligament distance. (Copyright © 2012 SAGE Publications. Reprinted with permission from Seitlinger et al.[7])

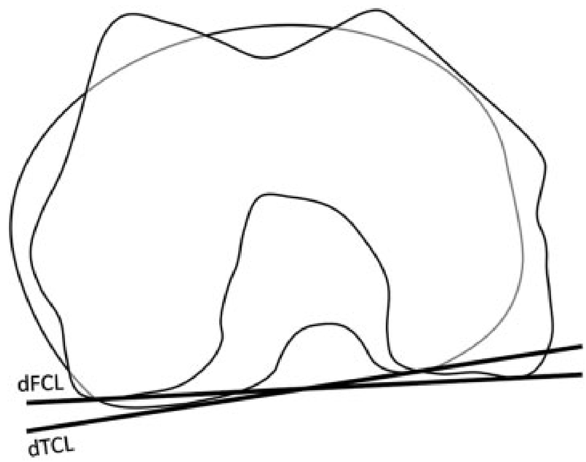

Fig. 3 Method for measuring knee rotation. The reference lines are the dTCL (posterior) and the dFCL (posterior). The angle between these lines is femoral tibial rotation. dFCL, dorsal femoral condylar line; dTCL, dorsal tibial condylar line. (Copyright © 2012 SAGE Publications. Reprinted with permission from Seitlinger et al.[7])

TT–TG and TT–PCL. For categorical analyses two cutoffs were used: one from literature and one calculated from the current study. The literature references used were $\geq$ 20 mm for the TT–TG and $\geq$ 24 mm for the TT–PCL.[19] For the current study, the abnormal values were calculated based on 2 SD from the control population, meaning 5% of the control population would be above that limit with a normal distribution.

Correlations were calculated by Pearson test between TT–TG and TT–PCL, TT–TG and knee rotation, and TT–PCL and knee rotation. The number of patients in each group of Dejour

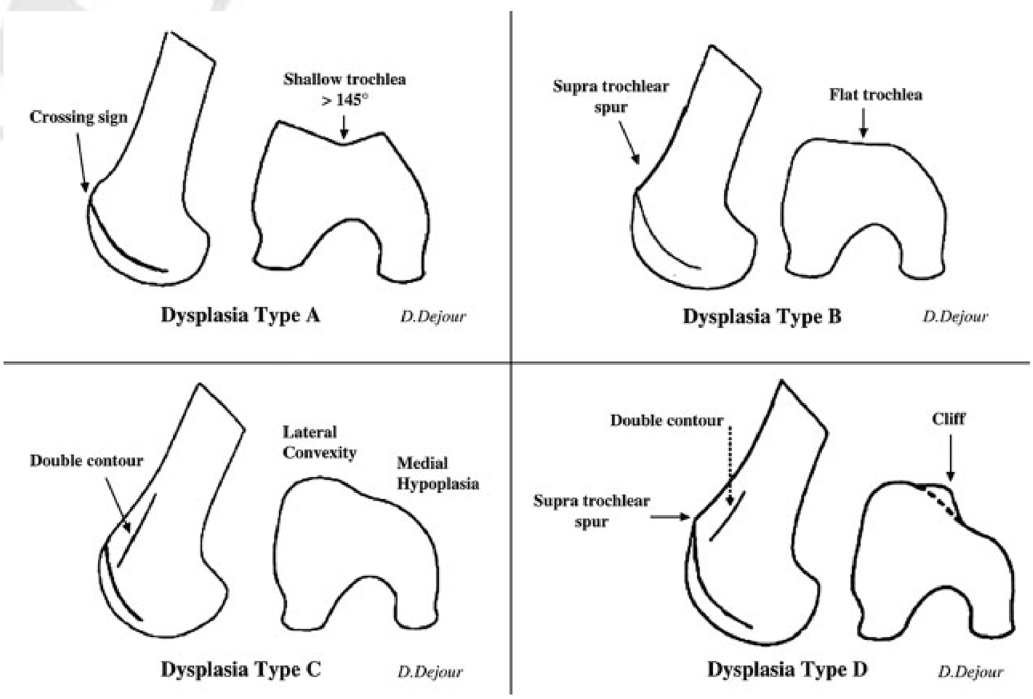

Fig. 4 Dejour classification of trochlear dysplasia. The Dejour classification is based on a true lateral radiograph. Type A has a shallow trochlear groove. Type B has a flat trochlea. Type C has medial hypoplasia and lateral trochlea facet convexity. Type D has the findings of type C plus a more prominent trochlear boss with extension distally creating a trochlear "cliff." (Copyright © 2007 Lippincott Williams & Wilkins. Reprinted with permission from Dejour et al.[6])

classification was determined. Statistical significance for all the tests was determined by a $p < 0.05$.

Results

The TT–PCL measurement showed excellent agreement for intraobserver variability (0.92) and interobserver variability (0.94). The TT–TG measurement showed excellent agreement for intra/interobserver variability (both 0.89). A statistically significant difference ($p < 0.001$) was found between the TT–TG distance of the control group (mean, 10.0 mm; SD, 3.8 mm) and the patellar instability group (mean, 14.5 mm; SD, 5.2 mm) (►**Fig. 5A**). A statistically significant difference ($p < 0.003$) was also found in the TT–PCL measurement between the control group (mean, 19.0 mm; SD, 4.5 mm) and the patellar instability group (mean, 21.6 mm; SD, 4.5 mm) (►**Fig. 5B**) (►**Table 1**). Mean knee rotation in the patellar instability group was 4 degrees (SD, 5 degrees).

The cutoff calculated for the sample in this study was 18 mm for the TT–TG and 28 mm for the TT–PCL. The number of patients above literature and the current study cutoff are in ►**Table 2**. Using the literature cutoff there were more patients, in the patellar instability and control groups, with abnormal TT–PCL than TT–TG, while using the current study cutoff there were more patients with abnormal TT–TG. In the instability group three patients had TT–TG ≥ 20 mm and TT–PCL ≥ 24 mm; and three patients had TT–TG ≥ 18 mm and TT–PCL ≥ 28 mm (two of them were above all cutoffs). There was a positive correlation between TT–TG and TT–PCL ($R^2 = 0.548$, $p < 0.001$). Knee rotation had a positive significant correlation with TT–TG ($R^2 = 0.434$, $p = 0.006$), but not with TT–PCL (►**Fig. 6**). In the instability group, 32 knees had trochlear dysplasia type A (76%), 7 had type B (16.5%), 2 had type C (5%), none had type D, and 1 had no trochlear dysplasia (2.5%).

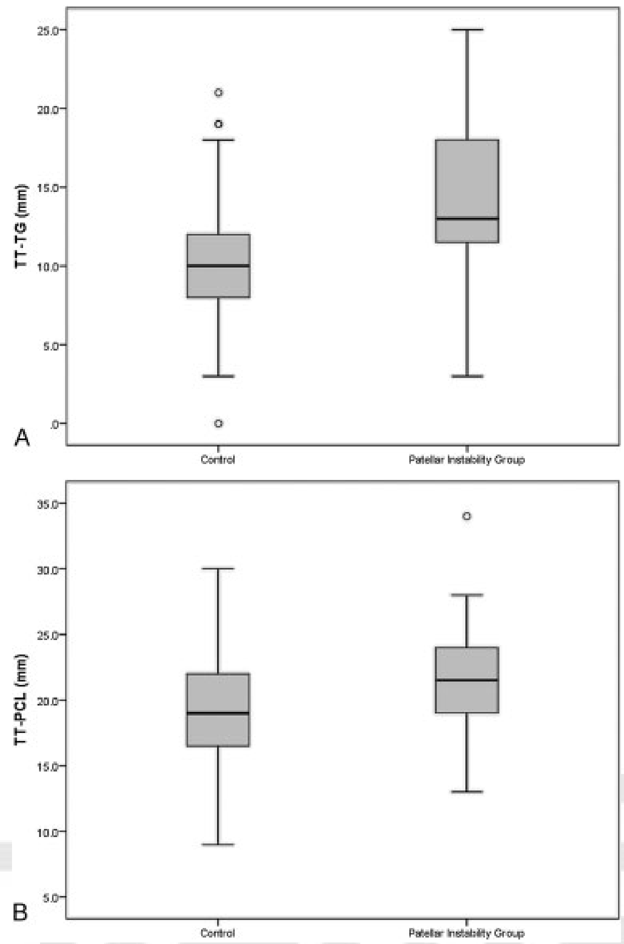

Fig. 5 Mean and SD in control and patellar instability groups for (A) TT–TG and (B) TT–PCL. SD, standard deviation; TT–TG, tibial tuberosity–trochlear groove distance; TT–PCL, tibial tuberosity–posterior cruciate ligament distance.

Table 1 Comparison of control versus patellar instability groups

Parameter	Control group			Patellar instability group			Min	Max
	Mean	SD	Min	Max	Mean	SD		
TT–TG	10.03	3.77	0	21	14.48	5.16	3	25
TT–PCL	19.04	4.51	9	30	21.62	4.52	13	34

Abbreviations: TT–TG, tibial tuberosity–trochlear groove distance; TT–PCL, tibial tuberosity–posterior cruciate ligament distance.

Table 2 Patients above cutoff

Cutoff		Patellar instability ($n = 42$)	Control ($n = 84$)	TT–TG + TT–PCL patellar instability group	TT–TG + TT–PCL control group	TT–TG + TT–PCL all patients
Literature	TT–TG ≥ 20 mm	7 (17%)	1 (1%)	3 (43%)	1 (100%)	4 (50%)
	TT–PCL ≥ 24 mm	14 (33%)	13 (15%)	3 (21%)	1 (8%)	4 (15%)
Current study	TT–TG ≥ 18 mm	12 (29%)	5 (6%)	3 (25%)	1 (20%)	4 (23.5%)
	TT–PCL ≥ 28 mm	5 (12%)	1 (1%)	3 (60%)	1 (100%)	4 (67%)

Abbreviations: TT–TG, tibial tuberosity–trochlear groove distance; TT–PCL, tibial tuberosity–posterior cruciate ligament distance; TT–TG + TT–PCL, patients with abnormal TT–TG and TT–PCL.

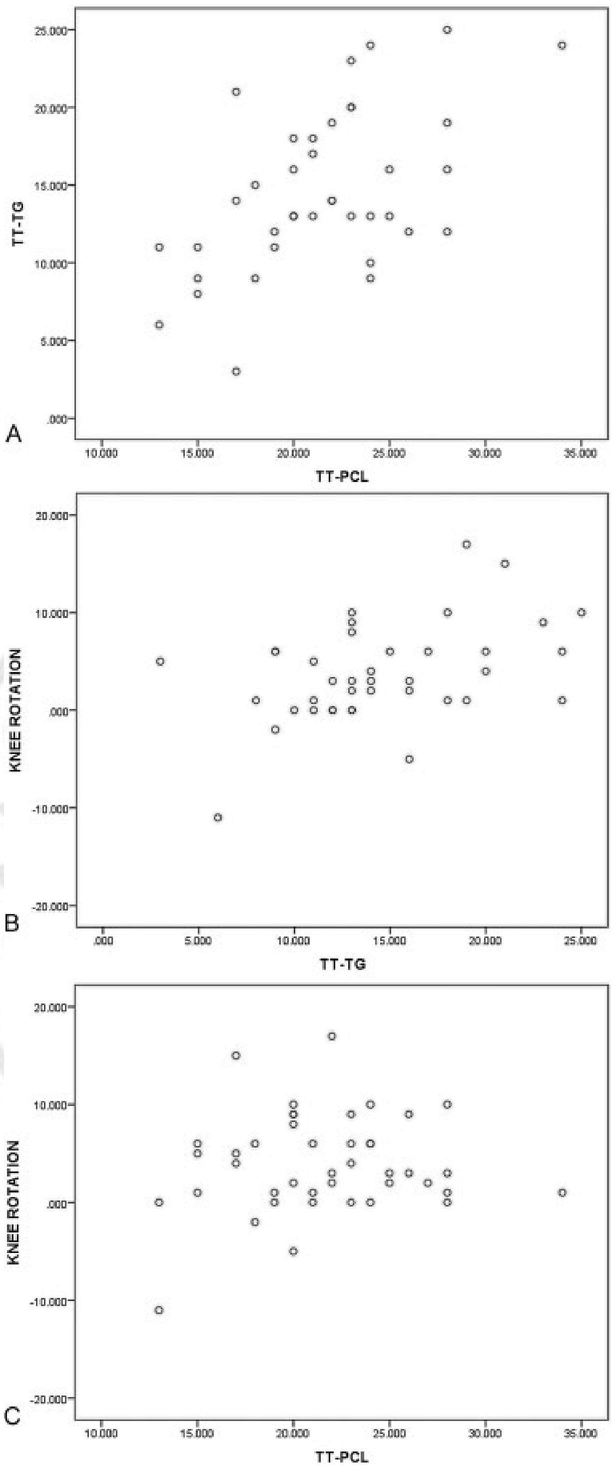

Fig. 6 Correlation between (A) TT–TG and TT–PCL, (B) TT–TG and knee rotation, and (C) TT–PCL and knee rotation. TT–TG, tibial tuberosity–trochlear groove distance; TT–PCL, tibial tuberosity–posterior cruciate ligament distance.

Discussion

An increase in the lateral position of the tibial tubercle is a significant risk factor for recurrence of patellar dislocation.[1,2,6–12,14] Historically, this has been quantified by the TT–TG distance and a measure larger than 20 mm is usually considered an indication for TT medialization.[1,2,6–12,14] However, Seitlinger et al[7] suggested that not all patients with a large TT–TG have an abnormal laterally positioned TT. Conditions, such as trochlear dysplasia, may decrease the meaningfulness of the TT–TG measurement by precluding the correct identification of the center of the TG.[7,8,16,17] The TT–TG may be increased not only with lateral positioning of the TT, but also secondary to distal femoral internal rotation, and/or trochlear dysplasia, which results in an atypical medial position of the TG. Before TT medialization or anteromedialization, it is necessary to thoroughly evaluate the etiology of the patient's excessively lateral tuberosity. If the malposition is due mostly to trochlear dysplasia, to femoral anteversion (with distal femoral internal rotation) or tibial external rotation, the site of the deformity should be the site of potential treatment, not tuberosity medialization (e.g., malrotation of the femur relative to the tibia also alters the TT–TG measurement).[7,8] While effective when indicated, tuberosity medialization when the tuberosity is in "normal position" may increase pressure on the medial facet of the patella and in the tibiofemoral joint, such as could be the case when the TT–TG and TT–PCL are within normal limits.[20–22] As a measurement referenced to the tibia, it is obviously independent of trochlear morphology and femoral rotation, the TT–PCL measurement was introduced as an adjunct in evaluating the TT position. Excellent intra- and interobserver variability among the examiners performing these measurements indicates both measurements are reliable and reproducible. The TT–PCL intraclass correlation coefficients from the present study are similar to those reported by Seitlinger et al[7] and other TT–TG studies.[9,12,23,24] An increased TT–TG distance correlates with recurrent patellar instability.[2,6–12] Dejour et al[6] found a mean TT–TG of 12.7 mm in 67 normal knees and 19.8 mm in 143 patients with patellar instability. Similarly, the current study demonstrated a statistically significant increase ($p < 0.001$) in the TT–TG measurements when comparing the instability group (mean, 14.5 mm) to the control group (mean, 10.2 mm). The current findings agree with the published literature for MRI studies (►**Table 3**).

Our measurements appear relatively lower than the results reported by the CT-based Dejour et al[6] study, but similar to MRI-based studies.[9,12,24,25] These follow the work of Camp et al,[9] who reported that CT and MRI TT–TG measurements are different. MRI measurements are 2.3 mm (mean) lower than CT measurements for distances < 20 mm and 4 mm (mean) lower for measurements ≥ 20 mm.[9] As the MRI measurements are lower than CT, the cutoff may actually be lower when using MRI measurements. This difference may explain the 56% prevalence of patients with the TT–TG ≥ 20 mm found by Dejour et al[6] using CT compared with the prevalence in the MRI studies.[6,9,10,23,26] The 17% prevalence of patients with abnormal TT–TG (≥ 20 mm) found in the current study is similar to the reported literature for MRI measurements (Camp et al,[9] 14%; Balcarek et al,[23] 6%; Balcarek et al,[10] 11%; and Kohlitz et al,[26] 15.3%).

In the present study, the TT–PCL means for the patellar instability and the control group were 21.62 mm (SD, 4.5) and

Table 3 Mean TT–TG distance in literature

Mean TT–TG distance	Pennock et al (2014) MRI-based	Balcarek et al (2011) MRI-based	Dejour et al (1994) CT-based	Current study
Control group	11.7 mm ($n = 180$)	10.6 mm ($n = 136$)	12.7 mm ($n = 67$)	10.2 mm ($n = 84$)
Instability group	16.3 mm ($n = 45$)	14.6 mm ($n = 109$)	19.8 mm ($n = 143$)	14.5 mm ($n = 42$)

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging; TT–TG, tibial tuberosity–trochlear groove.

19.04 mm (SD, 4.5), respectively, with a 2.6 mm difference between the groups statistically significant ($p = 0.003$). Our results are similar to Seitlinger et al,[7] whose means were 21.88 mm (SD, 4.3) and 18.42 mm (SD, 3.35) for patellar instability and control groups, respectively, with a 3.5 mm difference statistically significant ($p < 0.00001$). The slightly larger mean for our control group can be explained by our higher prevalence of patients with the TT–PCL ≥ 24 mm, 15%, compared with Seitlinger et al,[7] 5%. Although the means are similar between the current study and Seitlinger et al,[7] they found more patients with the TT–TG ≥ 20 mm than patients with the TT–PCL ≥ 24 mm, while in the current study we found more patients with abnormal TT–PCL than abnormal TT–TG for those cutoffs. In that study, in the subgroup of participants with a pathological (≥ 20 mm) TT–TG distance (40 knee joints), 43% (17 knee joints) had a normal (< 24 mm) TT-PCL; therefore, they concluded that those 43% of knee joints had a normal TT position despite a large TT–TG. We could not confirm these findings. In our study, in the instability group, there were more patients with abnormal TT–PCL than TT–TG (33% had a TT–PCL ≥ 24 mm, 17% had a TT–TG ≥ 20 mm), and three patients had both values abnormal. One possible explanation is a difference in the populations. Seitlinger et al[7] found a 33% prevalence of patients with abnormal (≥ 20 mm) TT–TG (patellar instability and control groups together), while we found 17% in the patellar instability group. Considering that the prevalence of patients with the TT–TG ≥ 20 mm is much higher in patients with patellar instability, Seitlinger et al[7] probably had more than 33% of the patients in the patellar instability group above that cutoff. As noted above, the reported prevalence of TT–TG ≥ 20 mm measured by MRI in patellar instability patients is between 6 and 17%.[9,10,23,26] Also, the cutoff of 24 mm for the TT–PCL was not as discriminatory between the patellar instability and control groups in our study (TT–PCL ≥ 24 mm, 33% in patellar instability group and 15% in the control group) as it was for Seitlinger et al.[7] Hence, with the conflicting results, whether the lateral position of the TT plays an important role in the deformities that enlarges the TT–TG remains unclear. It's also important to emphasize that further studies with larger samples may be needed as cutoff and clinical application are not consistent.

There was a positive correlation between TT–TG and TT–PCL ($R^2 = 0.548$) suggesting that the proximal tibia deformity measured in the TT–PCL is an important deformity measured in the TT–TG. This correlation is higher than the one found by Seitlinger et al ($R^2 = 0.34$).[7] Knee rotation is associated with patellar instability, and therefore, can enlarge the TT–TG as the tibia external rotation lateralizes the patellar tendon insertion.[27] Although Seitlinger et al[7] found a low correlation of knee rotation with the TT–TG ($R^2 = 0.1775$), we found knee rotation to have a moderate, and statistically significant, correlation with the TT–TG ($R^2 = 0.434$). Neither study showed a statistically significant correlation of knee rotation with the TT–PCL. Our findings support that knee rotation can contribute to enlarge the TT–TG and that this soft tissue deformity is not associated with proximal tibia osseous deformity (lateral position of the TT on the proximal tibia).

Trochlea dysplasia can, theoretically, also contribute to changes in the TT–TG. It could enlarge it when the TG is more medial than in nondysplastic grooves or reduce it if more lateral. Whether the trochlear dysplasia shifts the groove or not compared with nondysplastic trochlea in patients without patellar instability is yet unknown. As most of the patients in our population had low-grade trochlear dysplasia (Dejour type A), we couldn't statistically test the interference of different grades of dysplasia in the TT–TG; however, we can conclude that in a patellar instability population with low-grade trochlear dysplasia, the lateral position of the TT of the tibia and knee rotation contributes to the TT–TG differences among them.

There are limitations to this retrospective study. Although statistical significance was achieved, the number of subjects tested was relatively low. Furthermore, while the control group was comprised of patients without a history of patellar instability or pain, they did have other knee pathology, which led to their knee MRI (meniscus tear, ACL tear, loose bodies). Because our population is comprised of patients with low-grade trochlear dysplasia our findings are limited to this group of patients and cannot be generalized to patients with high-grade trochlear dysplasia (types B, C, or D). In spite of that, this is the population treated by the senior author (J.F.) and is probably similar to the general sports medicine surgeon. However, for the small group of surgeons who attend patients with high-grade trochlear dysplasia, our findings may not apply to their clinic.

Future Research

A recent study followed 34 patients with recurrent patellar dislocations. A total of 19 patients had a lateralized tibial tubercle demonstrated by an increased TT–TG and 15 patients had a normal TT–TG. All the patients were treated with a MPFL reconstruction without concomitant TT osteotomy.

Both groups improved after surgery and at final follow-up there was no statistically significant difference in Kujala and Lysholm scores.[28] While this addresses instability, it does not address long-term effects of possible altered PF contact area/stress. Thus, future research is needed to expand the current study to evaluate the postoperative measurement of TT–TG/TT–PCL and the long-term outcomes. It would be useful to expand the study to a wider dysplastic population, including larger numbers of all categories of dysplasia. In addition, the effect of femoral anteversion and tibial external rotation would be of interest.

Conclusion

The difference in TT–PCL distance between control and patellar instability patients is statistically significant. It is an independent factor from trochlear dysplasia and knee rotation while the TT–TG is influenced by those factors. Two clinically important points deserve highlighting. First, while statistically distinct, the absolute difference in tuberosity position as measured by either technique is small between the instability group and no instability group. This leads to the second point: it is critical to evaluate all contributing factors underlying a patient's recurrent instability before deciding upon tuberosity surgery—do not solely use imaging numbers to treat a patient.

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