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

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Background: The radiological work-up of patients with patellofemoral disorders continues to be debated. The interchangeability of the tibial tubercle–trochlear groove (TT-TG) distance between computed tomography (CT) and magnetic resonance imaging (MRI) has recently been questioned. In addition, a new measurement—the tibial tubercle–posterior cruciate ligament (TT-PCL) distance—has shown that not all patients with a pathological TT-TG distance (>20 mm) have lateralization of the tibial tubercle. Another factor to consider when looking at the position of the tibial tubercle is the knee joint rotation, defined as the angle between the femoral dorsal condylar line and the tibial dorsal condylar line.

Purpose: To determine, with a larger population, if the TT-TG measurements can be used interchangeably between CT and MRI and to confirm the correlation between the TT-PCL and TT-TG distances in determining tibial tubercle lateralization.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: Patients with patellofemoral disorders and MRI and CT scans of the same knee (n = 141) were identified. The TT-PCL, the knee joint rotation, and TT-TG were measured independently by 2 fellowship-trained orthopaedic surgeons. Thirty measurements were repeated on a separate occasion to allow for an assessment of the intrarater reliability. The intraclass correlation coefficient (ICC) was used to assess reliability of the measurements.

Results: The mean TT-TG was 4.16 mm less on MRI ($P < .05$), with the mean TT-TG ± SD being 17.72 ± 5.15 mm on CT (range, 6.97-31.33 mm) and 13.56 ± 6.07 mm on MRI (range, 2-30.04 mm). The ICC for each rater comparing the 2 imaging modalities was only fair (0.54 and 0.48). The mean TT-PCL measurement was 20.32 ± 3.45 mm (range, 10.11-32.01 mm) with excellent interobserver and intraobserver reliability (>0.75). Based on the TT-TG and TT-PCL measurements, 4 groups of patients can be established. When knee joint rotation is compared among groups, an increased TT-TG may result from true lateralization of the tibial tubercle, an increased knee joint rotation, or both.

Conclusion: Based on a statistically significant mean difference (4.11 mm) and only a fair ICC (0.54 and 0.48) for raters comparing the 2 modalities, the measurements for the TT-TG cannot be used interchangeably between CT and MRI. Therefore, currently accepted values for TT-TG based on CT scans should not be applied to an MRI scan. The TT-PCL measurement is a measure of true lateralization of the tibial tubercle, while the TT-TG is an amalgamated measure of true lateralization and knee joint rotation.

Keywords: tibial tubercle–trochlear groove; tibial tubercle–posterior cruciate ligament; knee; magnetic resonance imaging; computed tomography

The management of patients with patellofemoral pathological conditions remains a challenge. The biomechanics of the patellofemoral joint are complex and rely on the interplay between the soft tissue and osseous constraints of the knee. Establishing the exact cause of patellofemoral joint pain and instability can be difficult and requires an amalgamation of a detailed history, clinical examination, and radiological work-up, including plain film radiographs, computed tomography (CT), and/or magnetic resonance imaging (MRI). The work-up is the same for all patients with patellofemoral joint disorders, as no single factor differentiates patients with or without patellar instability.[2,5-7]

An important aspect in assessing patients with patellofemoral joint pain or instability is lateralization of the tibial tubercle (TT). This is most commonly assessed by measuring

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the mediolateral distance between the anterior TT and the deepest point of the trochlear groove (TG)—the TT-TG distance. Although originally described by Goutallier et al[10] in 1978 on an axial radiograph, in 1994 Dejour[7] popularized the use of CT to measure the TT-TG, improving the accuracy of this measurement.[20] Based on CT, a TT-TG <13 mm is commonly accepted as normal[3,7] and >15 mm as abnormal[1,14]; a TT-TG >20 mm is considered pathological[1,7,9,18] and is suggested in various treatment algorithms[1,7,9,17] as an indication for surgery in symptomatic patients.

The use of MRI in assessing patients with patellofemoral conditions has increased in popularity. The benefits include the ability to assess all soft tissue structures and the cartilage surfaces with no exposure to radiation.[1,12,19] Shoettle et al[15] compared the measurement of TT-TG on CT and MRI, and on the basis of 12 scans, they concluded that the measurement could be used interchangeably between the 2 modalities. Subsequently, many authors have used MRI to measure the TT-TG.[4,8,9,12,17] More recently, however, a second study of 59 scans[4] contradicted this conclusion, suggesting that measurements cannot be used interchangeably between the 2 modalities.

A variety of studies have highlighted factors that may affect the TT-TG measurement, including the degree of flexion of the knee and trochlear dysplasia.[1,8,16] To overcome these factors, Seitlinger et al[16] recently described a new measurement, the TT–posterior cruciate ligament (TT-PCL) distance, to quantify the position of the TT independent of the flexion of the knee and the shape of the trochlea. The TT-PCL is defined as the mediolateral distance, measured parallel to the posterior tibial dorsal line, between the medial border of the PCL at insertion and the midpoint of the patellar tendon at insertion. On the basis of their study, they defined a TT-PCL >24 mm as abnormal.[16] The authors concluded that although only 57% of the patients with a pathological TT-TG distance (>20 mm) had true lateralization of the TT in relation to the posterior cruciate ligament, the TT-PCL distance was a potential alternative method to determine the position of the TT.

The aim of our study was to

1. determine, with a larger population, if the TT-TG measurements could be used interchangeably between CT and MRI;
2. evaluate whether an acceptable inter- and intraobserver agreement can be obtained in the TT-PCL measurement; and
3. confirm the correlation between the TT-PCL measurement and TT-TG in determining TT lateralization.

METHODS

Before the project was started, approval was obtained from the hospital ethics committee. All patients with clinically significant patellofemoral joint pain or instability and with both MRI and CT scans of the same knee on the hospital picture archiving and communication system were identified for inclusion in the study. Patients were excluded if there was history of trauma or osteotomy of the affected limb and/or inadequate imaging that failed to show the necessary landmarks needed to carry out all measurements. The TT-PCL and TT-TG were measured independently by 2 fellowship-trained orthopaedic surgeons according to the methods used by Seitlinger et al[16] and Schoettle et al.[15] For the TT-PCL, we started by identifying the midpoint of the inferior patellar tendon insertion at the TT. The medial border of the PCL was then marked on the most inferior slice on which the PCL was still identified. Finally, the 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. Both points for the TT and PCL were then transferred onto this slice, and the distance between the 2 points was measured parallel to the dorsal condylar line (Figure 1).

For the TT-TG, the same point on the TT was used; the deepest point of the TG was then marked; and the femoral dorsal condylar line was defined. A line parallel to the femoral dorsal condylar line was used to measure the TT-TG (Figure 2). Finally, the knee joint rotation was measured as the angle between the femoral dorsal condylar and the tibial dorsal condylar line (Figure 3). Thirty scans were selected by systematic sampling, and all measurements were repeated by both evaluators on a separate occasion to allow for an assessment of the intrarater reliability.

Statistical Analysis

Statistical analysis was performed independently by a qualified medical statistician. Data were collected in Excel and analyzed using Statistica, version 11 (StatSoft Inc). Intraclass correlation coefficients (ICCs) were performed using R statistical computing software.

Continuous variables—including age, TT-TG, TT-PCL, and knee joint rotation—were analyzed descriptively using means and standard deviations as well as range. Sex, a categorical variable, was described using frequency distributions indicating absolute and relative frequencies. Agreement between measures was assessed using Bland-Altman plots, where the difference between measurements was plotted as a function of the average of the 2 measures. Mean deviations (from 0) as well as 95% confidence intervals were calculated to assist interpretation. ICC was used to assess reliability of the measurements.

Categorical variables were compared using a chi-square test for association. A comparison of the continuous measurements between 2 modalities was performed using a Student *t* test. For all analyses, a significance level of 5% was applied.

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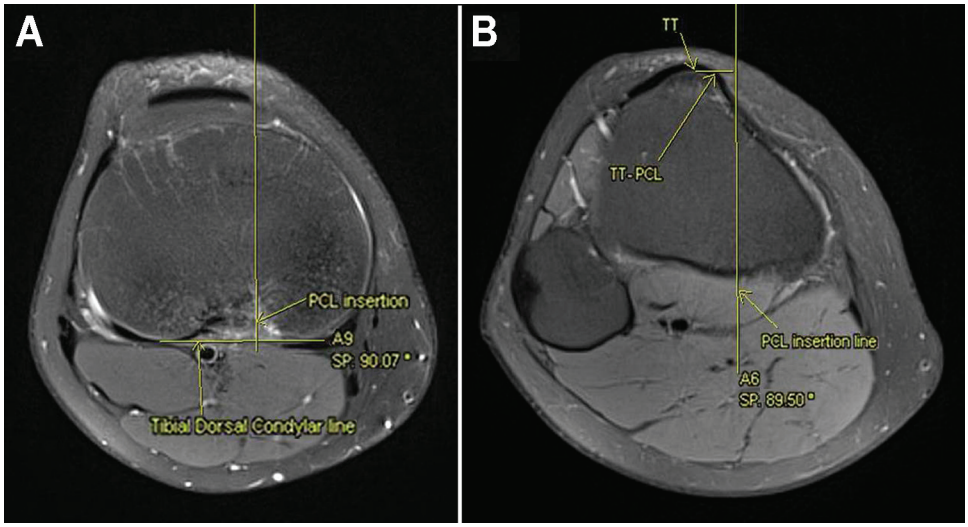

Figure 1. (A) Tibial tubercle–posterior cruciate ligament (TT-PCL) measurement. The PCL insertion line is drawn perpendicular to the tibial dorsal condylar line and along the medial aspect of the PCL. (B) The TT-PCL is the distance between the PCL insertion line and the TT, parallel to the tibial dorsal condylar line.

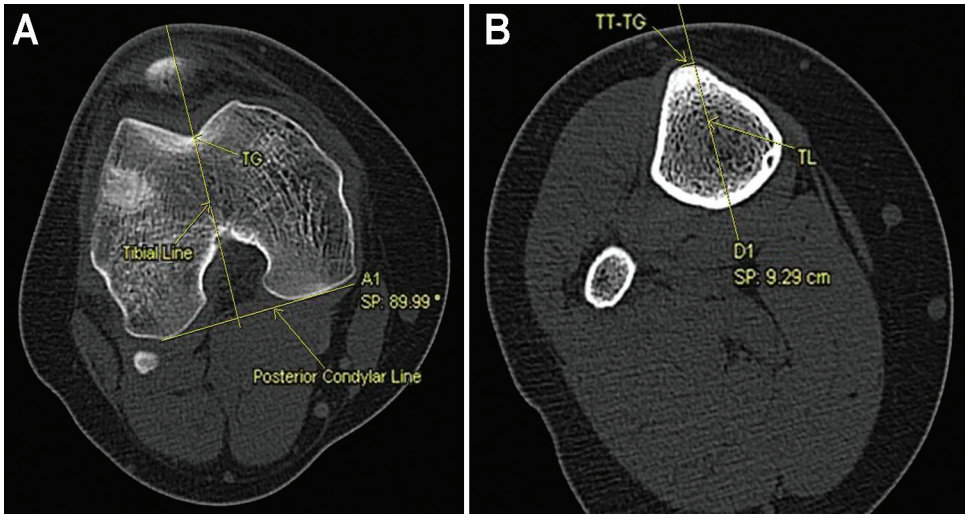

Figure 2. (A) Tibial tubercle–trochlear groove (TT-TG) measurement. The tibial line is drawn perpendicular to the femoral posterior condylar line. (B) The TT-TG is the distance between the tibial line (TL) and the TT, parallel to the femoral posterior condylar line.

RESULTS

Included in this study were 141 pairs of scans, from 108 female and 33 male patients with a mean ± SD age of 28.5 ± 11.13 years (range, 10-59 years). Overall, the mean TT-TG was 17.72 ± 5.15 mm on CT (range, 6.97-31.33 mm) and 13.56 ± 6.07 mm on MRI (range, 2-30.04 mm). The mean measurement was therefore 4.16 mm less on MRI scan, which was statistically significant ($P < .05$); this correlates with the 4.11-mm difference as calculated via Bland-Altman analysis. The TT-TG was >20 mm on 44 (31.2%) CT scans and 26 (18.4%) MRI scans. Note, however, that not all scans with a TT-TG >16 mm on MRI had a TT-TG above 20 mm on CT.

Regarding the individual TT-TG measurements on CT and MRI, the interobserver and intraobserver reliability was considered excellent (>0.89) according to the ICC for both modalities (Table 1). The Bland-Altman analysis confirmed these results with a mean difference of 0.24 mm and 0.29 mm on CT and MRI, respectively (Figures 4 and 5). The ICC for each rater comparing the 2 imaging modalities for TT-TG was only fair, with rater A being 0.54 and rater B being 0.48 (Table 1). This implies that the measurements cannot be used interchangeably between the 2 modalities. Thus, for further analysis of the comparative data with the TT-PCL, we used a TT-TG >20 mm on CT as abnormal. The average knee joint rotation measured on CT and MRI was 8.33° and 5.59°, respectively, which was

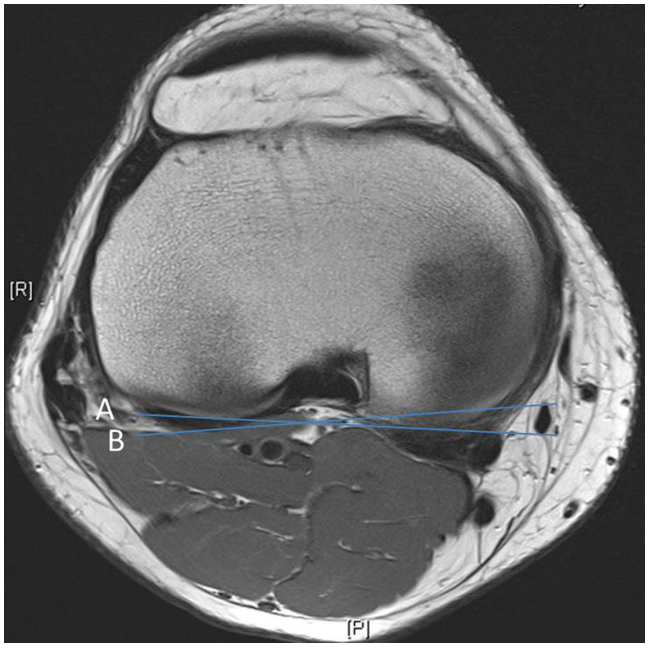

Figure 3. Knee joint rotation calculation. The tibial dorsal condylar line, A, and the femoral dorsal condylar line, B, were superimposed onto a single scan. The angle between A and B represents the knee joint rotation.

TABLE 1
Intraclass Reliability Calculations[a]

Reliability	ICC
Interrater	
TT-TG on CT	0.97
TT-TG on MRI	0.98
TT-PCL	0.92
Intermethod	
Rater A	0.54
Rater B	0.48

[a]CT, computed tomography; ICC, intraclass correlation coefficient; MRI, magnetic resonance imaging; PCL, posterior cruciate ligament; TG, trochlear groove; TT, tibial tubercle.

a statistically significant difference ($P < .0001$). We noted a moderate correlation between the TT-TG and the knee joint rotation. The correlation was stronger on CT ($r = 0.60$) than MRI ($r = 0.24$).

The mean TT-PCL measurement was 20.32 ± 3.45 mm (range, 10.11-32.01 mm) with only 14% (20 of 141) having an abnormal TT-PCL (>24 mm). Of this subgroup, 55% (11 of 20) had an abnormal TT-TG (>20 mm) on CT. Overall, 31% (44 of 141) of the patients in this study had an abnormal TT-TG on CT, with only 25% (11 of 44) of this group having an abnormal TT-PCL. The interobserver and intraobserver reliability was considered excellent (>0.92) for the TT-PCL according to the ICC.

On review of the results, it became apparent that lateralization of the TT can be due to true lateralization

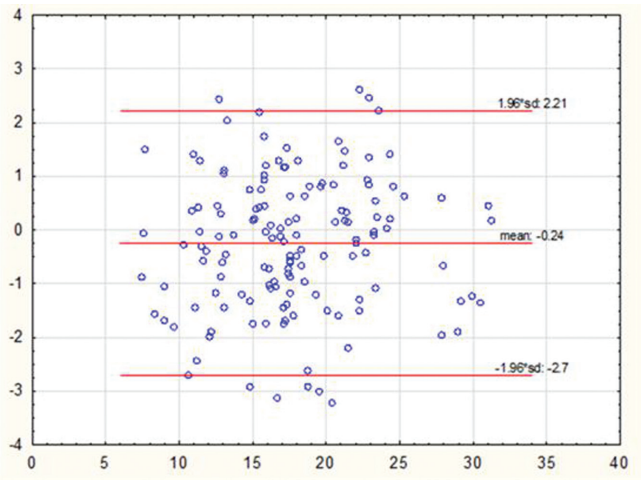

Figure 4. Bland-Altman analysis of interrater agreement between raters A and B for computed tomography.

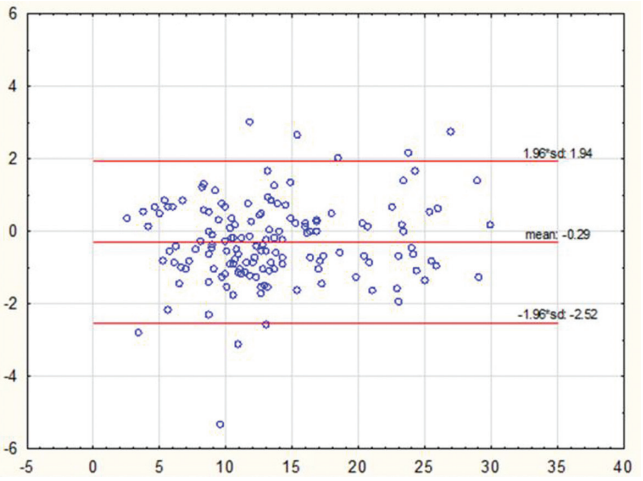

Figure 5. Bland-Altman analysis of interrater agreement between raters A and B for magnetic resonance imaging.

(demonstrated by an increased TT-PCL), increased rotation through the knee joint (normal TT-PCL but increased TT-TG), or both. To investigate these factors further, 4 groups of patients were established according to the recognized normal values for TT-TG (20 mm on CT) and TT-PCL (24 mm on MRI; Table 2). The knee joint rotation angle was then compared between the groups. A significant difference ($P < .05$) in knee joint rotation angle was noted between groups 1 and 3. This suggests that the increased TT-TG in group 3 was secondary to the increase in knee joint angle, given that the TT-PCL was normal in both groups, confirming no lateralization of the tubercle. A significant difference ($P < .05$) was also noted between groups 2 and 3. Group 2 had an abnormal TT-PCL, confirming lateralization of the tubercle, but a normal TT-TG. In this group, the knee joint angle was significantly lower than in group 3, thus reducing the TT-TG to within-normal limits (see Table 2).

TABLE 2
Grouping According to TT-TG on CT and TT-PCL on MRI[a]

	Normal TT-TG		Pathological TT-TG	
	Group 1[b]	Group 2[c]	Group 3[d]	Group 4[e]
Patients, No. (%)	88 (62.4)	9 (6.4)	33 (23.4)	11 (7.8)
Distance, mm, mean ± SD				
TT-TG	15.04 ± 3.12	15.06 ± 3.55	23.22 ± 2.77	25.42 ± 3.99
TT-PCL	18.92 ± 2.66	25.92 ± 2.42	20.82 ± 2.27	25.88 ± 1.75
KJA on CT, deg, mean	6.8	6.7	12.5	10.3

[a]CT, computed tomography; KJA, knee joint angle; MRI, magnetic resonance imaging; PCL, posterior cruciate ligament; TG, trochlear groove; TT, tibial tubercle.
[b]TT-TG, <20 mm; TT-PCL, <24 mm.
[c]TT-TG, <20 mm; TT-PCL, >24 mm.
[d]TT-TG, >20 mm; TT-PCL, <24 mm.
[e]TT-TG, >20 mm; TT-PCL, >24 mm.

DISCUSSION

To our knowledge, this is the largest study comparing the measurement of TT-TG on CT and MRI. First, our results confirm that—based on a statistically significant mean difference (4.11 mm) and only a fair ICC (0.54 and 0.48) between CT and MRI—measurements cannot be used interchangeably between the 2 modalities. Therefore, currently accepted values for TT-TG, which are based on CT scans, should not be applied to an MRI scan. Second, we established that an excellent inter- and intraobserver reliability can be obtained for the TT-PCL measurement. However, more work is required to establish its usefulness in patients with patellofemoral joint symptoms. Finally, we noted that on the basis of the TT-TG and TT-PCL, 4 separate groups of patients can be established. When comparing knee joint rotation among groups, we noted that an increased TT-TG may result from true lateralization of the TT, an increased knee joint rotation, or both.

This study concurs with that of Camp et al,[4] who came to the same conclusion based on 59 scans in patients with patellofemoral joint instability. Although both studies showed that the figures are not interchangeable, the mean differences between the modalities varied. Camp et al[4] noted that the average TT-TG was 2.23 mm less on MRI in all patients and 3.8 mm in the subgroup of patients with a TT-TG >20 mm on CT, which compares with 4.11 mm in all patients in our study. These differences may be due to the variations in MRI protocols, MRI scanners, and the use of different knee coils. Using a knee coil has been shown to induce a degree of flexion of the knee and therefore reduce the TT-TG.[1] Although all the measurements were routinely lower on MRI in the study by Camp et al,[4] this was not the case in our study. We believe, therefore, that one cannot simply subtract the difference from the established values; the normal and pathological measurements for TT-TG on MRI, along with a standardized protocol, still need to be established.

In keeping with our study, various studies have shown that an excellent ICC can be achieved.[4,11,15,20] We also demonstrated an excellent inter- and intraobserver reliability with an ICC of 0.92 for the TT-PCL. This was better than the 0.74 in the original study by Seitlinger et al.[16] Note, however, that the original study included a general practitioner with poor MRI experience to perform the measurements.

When comparing our cohort with that of Seitlinger et al,[16] we found true lateralization of the TT (TT-PCL >24 mm) in only 14% of patients and 31% when using the traditional TT-TG distance of >20 mm on CT, compared with 38% and 59% in their study. In addition, they noted that 57% of patients with an abnormal TT-TG had an abnormal TT-PCL, as opposed to only 25% in our study. These differences may in part be explained by the different patient populations studied with potential geographical variations in anatomic parameters. While their population had a high percentage of instability patients, the association between lateralization of the TT and instability has been questioned, with no statistical difference seen between patients with only pain.[5]

Previous studies have highlighted the effect of flexion and extension of the knee and the changes in knee joint rotation due to the screw-home effect.[8,13,21] As the knee moves from flexion into the final 20° of extension, the tibia externally rotates on the femur. Naturally, it follows that external rotation of the tibia through the knee joint would result in lateralization of the TT and an increased TT-TG. In conjunction with the lower values for TT-TG on MRI, we also showed a significantly lower knee joint rotation on MRI (5.59°) compared with CT (8.33°). This is likely to be related to the difference in imaging protocols between modalities, with increased flexion of the knee with the use of a MRI knee coil.

The relationship between an increased knee joint rotation and an increased TT-TG has been documented.[16,18] In agreement with this, we demonstrated a moderate correlation between the TT-TG and the knee joint rotation. The correlation was stronger on CT than MRI. There is, however, a group of patients who do not follow this relationship, thereby highlighting that the TT-TG is influenced by a variety of factors. On the basis of the TT-TG and TT-PCL measurements, patients can be divided in 4 groups (Table 2). Group 1 contained the majority (62.5%) of the patients and was normal according to both

measurements. Group 4 contained 7.8% of patients and had lateralization of the TT based on both measurements. In addition, 2 further groups emerged: group 2 (6.3% of patients), having lateralization of the TT as determined by an abnormal TT-PCL (and normal TT-TG), and group 3 (23.4% of patients), having an abnormal TT-TG (and a normal TT-PCL). The statistically significant difference in knee joint angle between groups 1 and 3 highlights the effect that knee joint rotation can have on the TT-TG measurement. This demonstrates that lateralization of the TT can be due to true lateralization of the TT and/or secondary to an increased knee joint rotation. Traditionally, patients in group 2 would not be considered for distal realignment surgery based on their TT-TG (despite their having lateralization of the tubercle); conversely, tubercle osteotomy in some patients in group 3 may result in excessive medialization. The clinical relevance of these 2 groups requires further investigation; their patellofemoral dysfunction may represent a more dynamic interaction between the anatomic alignment and the soft tissue constraints around the knee that influence knee joint rotation. This may also be 1 factor contributing to variation in the results obtained in some patients after TT transfers.

One weakness of this study is that it was conducted retrospectively; thus, the exact detail of each scan and the amount of flexion that the knee was in at the time of the scan were therefore not available. Although this may be considered a weakness, it is a common situation that orthopaedic surgeons face with investigations being performed elsewhere before referral.

In conclusion, the measurements for the TT-TG cannot be used interchangeably between CT and MRI. Therefore, currently accepted values for TT-TG, which are based on CT scans, should not be applied to an MRI scan. Second, the TT-PCL distance is a useful radiological measurement that provides a measure of true lateralization of the TT. More work is required to further define the normal TT-PCL distance and its role in the assessment of patients with patellar femoral pathological conditions. Finally, lateralization of the TT can occur as a result of true lateralization of the TT and/or an increased knee joint rotation. The TT-PCL measurement is a measure of true lateralization of the TT where the TT-TG is an amalgamated measure of true lateralization and knee joint rotation.

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