CrossMark

KNEE

The contribution of the tibial tubercle to patellar instability: analysis of tibial tubercle–trochlear groove (TT-TG) and tibial tubercle–posterior cruciate ligament (TT-PCL) distances

Mark J. Heidenreich[1] · Christopher L. Camp[1] · Diane L. Dahm[1] · Michael J. Stuart[1] · Bruce A. Levy[1] · Aaron J. Krych[1]

Abstract

Purpose The purpose of this study is to assess the reliability of measuring the tibial tubercle to posterior cruciate (TT-PCL) distance compared to the tibial tubercle to trochlear groove (TT-TG) distance on magnetic resonance imaging (MRI), establish baseline TT-PCL values in patellar instability patients, and determine the predictive value of an excessive TT-PCL distance (≥ 24 mm) for recurrent patellar instability compared to a TT-TG distance ≥ 20 mm.

Methods TT-TG and TT-PCL distances were calculated on MRI in a randomized and blinded fashion by two reviewers on 54 patients (59 knees) with patellar instability. Interobserver reliability was assessed using interclass correlation coefficients (ICC). TT-PCL distances were also assessed to establish mean values in patellar instability patients. The ability of excessive TT-PCL and TT-TG distances to predict recurrent instability was assessed by comparing odds ratios, sensitivities, and specificities.

Results Interobserver reliability was excellent for both TT-TG (ICC = 0.978) and TT-PCL (ICC = 0.932). The mean TT-PCL in these 59 knees was 21.7 mm (standard deviation 4.1 mm). Twelve (20 %) of 59 knees had a single dislocation, and 47 (80 %) exhibited 2 or more dislocations. The odds ratios, sensitivities, and specificities of a TT-TG distance ≥ 20 mm for identifying patients with recurrent dislocation were 5.38, 0.213, and 1.0, respectively, while those of a TT-PCL distance ≥ 24 mm were 1.46, 0.298, and 0.583, respectively. Of the 10 knees with a TT-TG distance ≥ 20 mm, all 10 (100 %) had recurrent instability, while 14 (73.7 %) of the 19 knees with a TT-PCL ≥ 24 mm experienced multiple dislocations (n.s.).

Conclusion Both TT-PCL and TT-TG can be measured on MRI with excellent interobserver reliability. In this series, the mean TT-PCL value in patients with patellar instability was 21.8 mm, but the range was broad. A TT-PCL distance ≥ 24 mm was found to be less predictive of recurrent instability in this series. For patients experiencing multiple episodes of patellar instability in the setting of a normal TT-TG distance, obtaining the TT-PCL measurement may provide a more focused assessment of the tibial contribution to tubercle lateralization.

Level of evidence III.

Keywords Patellar instability · Tibial tubercle to trochlear groove distance · Tibial tubercle to posterior cruciate ligament distance

✉ Aaron J. Krych
krych.aaron@mayo.edu

1 Department of Orthopedic Surgery and Sports Medicine, Mayo Clinic and Mayo Foundation, Mayo Clinic 200 First St., SW, Rochester, MN 55905, USA

Introduction

Patellofemoral joint instability is a common clinical challenge. Previous studies describe annual first-time dislocation rates as high as 29–43 per 100,000 in certain populations, with the majority of episodes occurring during sporting activities [12, 15]. Upon failure of conservative measures, recurrent patellofemoral instability often requires surgical management. Procedures typically focus on restoration of proximal soft tissue structures, such as the medial patellofemoral ligament (MPFL), correction of a lateralized tibial tubercle, or a combination of both [1, 9, 14, 19]. The decision to perform a distal realignment procedure is usually impacted by the tibial tubercle to trochlear groove (TT-TG) measurement. This parameter evaluates

the position of the tibial tubercle relative to the femoral trochlea, with increasing values suggesting a more lateralized position. A computed tomography (CT) TT-TG distance ≥20 mm is helpful in identifying patients at risk for subsequent patellar instability episodes [2–4, 11], and in the appropriate clinical setting, distal realignment surgery may be warranted [8, 10].

Criticism of the TT-TG distance in surgical decision-making has driven the ongoing search for more reproducible, applicable, and predictive measures. Limitations of the TT-TG distance include its reliance on an often dysplastic trochlea and the use of a strict cut-off value (20 mm) that does not respect patient-specific size nor anatomy [7, 13]. It is also unable to distinguish the individual contributions of an internally rotated trochlea (as in increased femoral anteversion) and a lateralized tibial tubercle to overall patellofemoral malalignment. Recently, Seitlinger et al. described the tibial tubercle to posterior cruciate ligament (TT-PCL) distance measured on magnetic resonance imaging (MRI) as a means to overcome some of these limitations. Similar to the TT-TG distance, a TT-PCL distance does not address potential confounders such as patient body habitus. However, a potential major advantage of the TT-PCL measurement is its independence of femoral anatomy and anteversion. As a result, it is postulated to be a more pure assessment of isolated tubercle lateralization on the tibia. Their data suggested a TT-PCL distance ≥24 mm to be pathologic [17]; however, use of the TT-PCL measurement has not yet been validated in the literature.

Therefore, this study further investigates the application of the TT-PCL measurement in a cohort of patients with known patellar instability. Specifically, our purpose was to evaluate the interrater reliability of measuring TT-PCL distance on magnetic resonance imaging (MRI) compared to MRI TT-TG distance, attempt to establish baseline TT-PCL values in patients with patellar instability, and assess the predictive value of an excessive TT-PCL distance ≥24 mm on recurrent patellar instability compared to a TT-TG distance of ≥20 mm.

Materials and methods

After obtaining institutional review board approval, medical records were searched to identify all patients with a diagnosis of patellar instability, defined as at least one dislocation event, at our institution from 2003 to 2011. All diagnoses were made by patient history and clinical examination by a sports medicine fellowship-trained orthopaedic surgeon and documented in the patient's record. A total of 54 patients with a mean follow-up of 6.6 years had MRI of the affected knee and were included in this study. Five of 54 patients had bilateral patellar instability, providing a
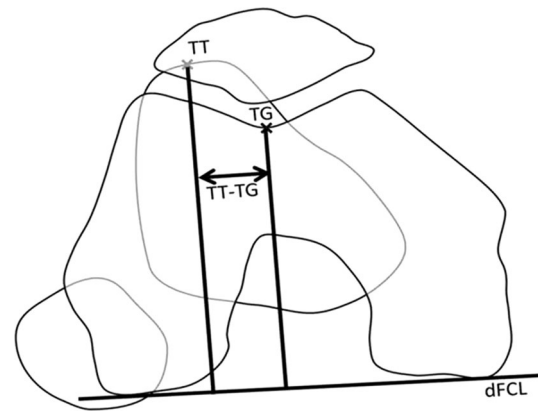
Fig. 1 Transposed images demonstrating TT-TG. *TT* tibial tubercle, *TG* trochlear groove, *dFCL* distal femoral condylar line. Reproduced with permission from Seitlinger et al. [17] Sage publications

total of 59 knees for the investigation. This cohort is also described in a previous study [6].

Using a previously validated technique [5], the TT-TG and TT-PCL distances for all patients were obtained from MRI studies by a sports fellowship-trained orthopaedic surgeon and a senior orthopaedic resident. All images were evaluated electronically using QREADS Clinical Image Viewer (version 5.5.0, Mayo Clinic). This software allows distances to be measured to the nearest tenth millimetre. Measurements were taken in a blinded and randomized fashion, with each observer unaware of patient identity, clinical details, measurements taken by the other observer, and previous measurements taken from the images being evaluated.

Magnetic resonance imaging was carried out with the patient in the supine position with the knee in full extension. The lower extremity of interest was padded for stability to avoid motion. All studies generated T2-weighted fat-saturated axial images using a 1.5-T or 3.0-T General Electric MRI scanner (GE Healthcare, Waukesha, Wisconsin), with 3–4 mm thickness cuts collected over 4–4 min and 30 s [6]. Images of the previously published cohort of 49 patients by Seitlinger et al. were collected in a similar fashion with patients in the supine position, knee fully extended, and extra precautions taken to ensure stability of the joint throughout the scan. In that study, a Philips Panorama 1.0-T MRI scanner (Philips Healthcare, Andover, Massachusetts) was used to obtain T1-weighted axial images with 4 mm thickness cuts collected over 3 min and 41 s [17].

The TT-TG measurements on MRI were taken using a technique previously described [5] (Fig. 1). First, the image slice containing the deepest point of the bony trochlear groove was identified. On this image, a posterior condylar reference line was drawn tangential to the

posterior condyles and a trochlear line (TL) was drawn perpendicular to this, coursing through the deepest portion of the trochlear groove. This line was then transposed to the most cephalad image of the tibial tubercle in which the patellar tendon insertion could still be identified. On this image, the width of the tibial tubercle was measured and halved to define the centre of the tubercle. The perpendicular distance between the centre of the tibial tubercle on this image and the TL comprised our TT-TG measurement.

The TT-PCL measurements were taken using the protocol described by Seitlinger et al. (Fig. 2) [17]. First, the insertion of the PCL on the tibia was located by identifying the most caudal axial image slice in which the PCL was clearly identifiable. A horizontal reference line was drawn along the dorsal aspect of the proximal tibia. Perpendicular to this reference line, another line (denoted PL) was drawn adjacent to the medial aspect of the PCL. The PL line was then transposed to the most cephalad image of the tibial tubercle in which the patellar tendon insertion could still be identified. The centre of the tibial tubercle was defined as it was for the TT-TG technique above. The perpendicular distance between the centre of the tibial tubercle and the PL comprised our TT-PCL measurement.

This study was approved by the Mayo Clinic Institutional Review Board (IRB Approval ID# PR10-008026-03).

Statistical analysis

Interobserver reliability was assessed using interclass correlation coefficients (ICC), and agreement greater than 0.75 was considered excellent [18]. The TT-PCL distances were compared to a previously published cohort of 49 patients (58 knees) [17] to establish baseline values in a total of 117 knees exhibiting patellar instability. Finally, the ability of TT-PCL and TT-TG distances to predict recurrent instability (defined as ≥ 2 dislocation events) was assessed by comparing the sensitivity and specificity of excessive TT-PCL (≥ 24 mm) and TT-TG (≥ 20 mm) distances. Because the cohort was comprised of a complete series of patients diagnosed with patellar instability between 2003 and 2011, sample size calculations were not performed a priori. However, a power analysis was conducted to determine the size of differences detectable with 80 % power given the observed number of patients with >1 occurrence of patellar instability (overall rate 80 %). With 8 patients having TT-TG ≥ 20 mm and 51 having TT-TG <20 mm, there was 80 % power to detect differences of 75 versus 26 %, or 100 versus 58 %. Similarly, with 43 patients having TT-PCL ≤ 24 mm and 16 patients having TT-PCL >24 mm, there was 80 % power to detect differences of 75 versus 36 %, or 100 versus 75 %. All power calculations are based on a two-sided test with alpha = 0.05. Additional predictive
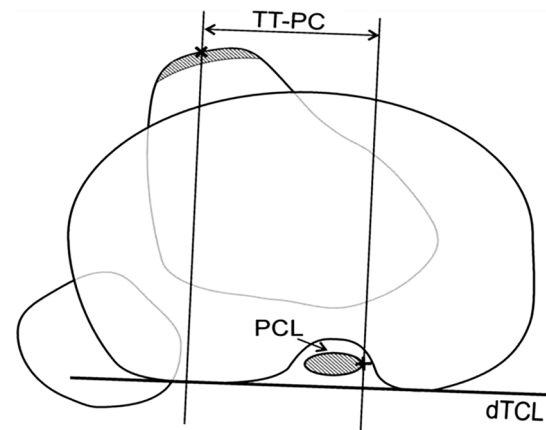
Fig. 2 Transposed images demonstrating TT-PCL. *TT* tibial tubercle, *PCL* posterior cruciate ligament, *dTCL* distal tibial condylar line. Reproduced with permission from Seitlinger et al. [17] Sage publications

analysis was performed by determining the recurrent instability odds ratios of excessive TT-PCL (≥ 24 mm) and TT-TG (≥ 20 mm) distances. Where odds ratios are present, 95 % confidence intervals (CI) are included. When comparing means of two groups (i.e. mean TT-TG of first-time dislocators to recurrent dislocators), variables were considered to be continuous and normally distributed, and a student t test was used to determine statistical significance. When comparing proportions of categorical data, a Fischer's exact test was utilized. P values <0.05 were considered significant.

Results

The mean patient age at the time of MRI scan was 22 years (SD 8.2 years) (Table 1). Twenty-four patients were male, and 30 were female. Twenty-eight of the knees were right, and 31 were left. Of the 59 knees included in the study, 12 (20 %) had a single traumatic dislocation, while the remaining 47 (80 %) exhibited 2 or more dislocations at a mean follow-up of 6.6 years.

The mean TT-TG distance measured by observer 1 was 15.2 mm (SD 5.5 mm) compared to 15.5 mm (SD 5.4 mm) for observer 2 (Table 2). The overall mean TT-TG distance for this cohort was 15.3 mm (SD 5.4 mm) with 10 knees demonstrating a TT-TG distance ≥ 20 mm. Interobserver reliability for calculating TT-TG distance on MRI was considered excellent (ICC = 0.978). The mean TT-PCL distance measured by observer 1 was 21.7 mm (SD 4.2 mm) compared to 21.6 mm (SD 4.3 mm) for observer 2, with an overall mean TT-PCL distance of 21.7 mm (SD 4.1 mm). Nineteen knees demonstrated a TT-PCL distance ≥ 24 mm. Similar to TT-TG distance, interobserver reliability of

Table 1 Demographics

	1 Dislocation event[a] (n = 12 knees)	≥2 Dislocation events[a] (n = 47)	All patients (n = 54)
Mean age at MRI (year)	26 ± 8	22 ± 8	22 ± 8
Male/female	7:3	17:27	24:30
Right/left	7:3	21:28	28:31

[a] Duplicate values from bilateral patients excluded for accurate statistics

Table 2 TT-TG versus TT-PCL reliability

	Observer 1	Observer 2	Combined	ICC[a]
Mean TT-TG (mm)	15.2 ± 5.5	15.5 ± 5.4	15.3 ± 5.4	0.978
Mean TT-PCL (mm)	21.7 ± 4.2	21.6 ± 4.3	21.7 ± 4.1	0.932

[a] ICC > 0.75 was considered to represent excellent agreement

Table 3 Ability of measures to predict recurrent instability

	Odds ratio (95 % confidence interval)	Sensitivity	Specificity
TT-TG ≥ 20 mm	5.38 (0.59, 713.83; n.s.)	0.213	1.000
TT-PCL ≥ 24 mm	1.46 (0.31, 6.92; n.s.)	0.298	0.583

TT-PCL measurements for this cohort was considered excellent (ICC = 0.932).

For knees with 1 dislocation ($n = 12$), the mean TT-TG distance was 13.3 mm (SD 4.1 mm), and for those with ≥2 dislocations ($n = 47$), the mean was 15.9 mm (SD 5.6 mm) (n.s.). The mean TT-PCL distances were 22.5 mm (SD 3.5 mm) and 21.5 mm (SD 4.3 mm), respectively (n.s.). All 10 (100 %) knees with a TT-TG ≥20 mm experienced multiple dislocation episodes, but only 14 of the 19 knees (73.7 %) with a TT-PCL ≥24 mm experienced recurrent instability (n.s.). In this cohort, the sensitivity and specificity of excessive TT-TG distance (≥20 mm) identifying patients with recurrent dislocation were 0.213 and 1.000, respectively (Table 3). The sensitivity and specificity of an excessive TT-PCL (≥24 mm) were 0.298 and 0.583, respectively. An excessive TT-TG distance (≥20 mm) demonstrated an odds ratio of 5.38 (95 % CI 0.59, 713.83; n.s.) for predicting recurrent instability, while the odds ratio of an excessive TT-PCL distance (≥24 mm) was 1.46 (95 % CI 0.31, 6.92; n.s.).

Discussion

Important findings of the present study include validation of interobserver reliability for obtaining TT-PCL measurements on MRI and demonstration of TT-TG values ≥20 mm as a stronger predictor of recurrent patellar instability than TT-PCL values ≥24 mm. The TT-PCL distance, as described by Seitlinger et al., allows isolated assessment of tubercle lateralization on the tibia; however, this measure appears to be less predictive of recurrent instability than TT-TG alone. In addition, this study identifies a mean baseline TT-PCL distance of 21.7 mm in patients with patellar instability.

Similar to Seitlinger et al. [17], these results indicate that the TT-TG distance and TT-PCL distance can both be reliability measured on MRI between raters (ICC 0.978 and 0.932, respectively). While previous studies have confirmed the precision of the TT-TG measurement, [16, 20] establishing the reliability of interobserver TT-PCL measurement is not as well reported. Furthermore, by combining our TT-PCL measurements with the previously published patient cohort [17], we were able to establish a mean TT-PCL value of 21.8 mm in 117 knees exhibiting patellar instability, though a broad range was observed (9.1–32.0 mm). The mean TT-PCL distances differed by only 0.2 mm (21.7 vs. 21.9, n.s.) between the two studies.

Finally, a TT-TG distance of ≥20 mm was a stronger predictor of recurrent instability (odds ratio 5.38; specificity 1.000) compared to an excessive TT-PCL distance ≥24 mm (odds ratio 1.46; specificity 0.538) in this series. Since the TT-PCL measurement is not subject to femoral influence, it likely represents a more accurate measure of pure tubercle lateralization on the tibia. This measure may be useful in assessing the need for tibial tubercle medialization; however, complete avoidance of the femur does not allow for evaluation of overall rotational malalignment. For example, a TT-PCL value may be normal (<24 mm) in a patient with a TT-TG ≥20 mm if severe femoral internal rotation or trochlear medialization exists. Conversely, a patient with a normal TT-TG (<20 mm) could have an excessive TT-PCL distance (≥24 mm) if significant femoral external rotation or trochlear lateralization exists with concomitant tubercle lateralization on the tibia. Further, the low sensitivity of TT-TG and TT-PCL measurements in this study may support use of both for more exact characterization of the unstable patella.

Limitations of this study include a relatively small sample size and retrospective design. The results are reflective of patellar instability patients alone and do not consider patients without symptomatic instability. Additionally,

intrarater reliability assessment was not performed since our techniques of TT-TG and TT-PCL assessment have been previously validated, and the inter-rater reliability was considered excellent [5, 6]. Nonetheless, this study represents a patient population commonly encountered by many orthopaedic surgeons and may have wide applicability as our knowledge of patellar instability expands.

Although TT-PCL may not be the only measure required for determining when to perform a tibial tubercle osteotomy, it may provide valuable information regarding the contribution of the tibia to tubercle lateralization. In clinical practice, evaluation of patients experiencing multiple episodes of instability, yet demonstrating a normal TT-TG distance, may be assisted by assessment of the TT-PCL distance. Ultimately, the fact that TT-TG distance quantifies the overall rotational alignment across the knee may make this parameter a better predictor of recurrent patellar instability.

Conclusion

Overall, both TT-PCL and TT-TG distances can reliably be measured on MRI with excellent interobserver reliability. In this series, the mean TT-PCL value in patients with patellar instability was 21.7 mm, but the range was broad. Ultimately, a TT-PCL distance ≥24 mm may be less predictive of recurrent instability than a TT-TG distance ≥20 mm.

Compliance with ethical standards

References

1. Arendt EA, Fithian DC, Cohen E (2002) Current concepts of lateral patella dislocation. Clin Sports Med 21(3):499–519
2. Balcarek P, Jung K, Ammon J, Walde TA, Frosch S, Schuttrumpf JP, Sturmer KM, Frosch KH (2010) Anatomy of lateral patellar instability: trochlear dysplasia and tibial tubercle-trochlear groove distance is more pronounced in women who dislocate the patella. Am J Sports Med 38(11):2320–2327
3. Balcarek P, Jung K, Frosch KH, Sturmer KM (2011) Value of the tibial tuberosity-trochlear groove distance in patellar instability in the young athlete. Am J Sports Med 39(8):1756–1761
4. Beaconsfield T, Pintore E, Maffulli N, Petri GJ (1994) Radiological measurements in patellofemoral disorders. A review. Clin Orthop Relat Res 308:18–28
5. Camp CL, Heidenreich MJ, Dahm DL, Bond JR, Collins MS, Krych AJ (2014) A simple method of measuring tibial tubercle to trochlear groove distance on MRI: description of a novel and reliable technique. Knee Surg Sports Traumatol Arthrosc. doi:10.1007/s00167-014-3405-7
6. Camp CL, Stuart MJ, Krych AJ, Levy BA, Bond JR, Collins MS, Dahm DL (2013) CT and MRI measurements of tibial tubercle-trochlear groove distances are not equivalent in patients with patellar instability. Am J Sports Med 41(8):1835–1840
7. Caplan N, Lees D, Newby M, Ewen A, Jackson R, St Clair Gibson A, Kader D (2014) Is tibial tuberosity-trochlear groove distance an appropriate measure for the identification of knees with patellar instability? Knee Surg Sports Traumatol Arthrosc 22(10):2377–2381
8. Caton JH, Dejour D (2010) Tibial tubercle osteotomy in patellofemoral instability and in patellar height abnormality. Int Orthop 34(2):305–309
9. Colvin AC, West RV (2008) Patellar instability. J Bone Joint Surg Am 90(12):2751–2762
10. Dejour D, Le Coultre B (2007) Osteotomies in patello-femoral instabilities. Sports Med Arthrosc 15(1):39–46
11. Dejour H, Walch G, Nove-Josserand L, Guier C (1994) Factors of patellar instability: an anatomic radiographic study. Knee Surg Traumatol Arthrosc 2(1):19–26
12. Fithian DC, Paxton EW, Stone ML, Silva P, Davis DK, Elias DA, White LM (2004) Epidemiology and natural history of acute patellar dislocation. Am J Sports Med 32(5):1114–1121
13. Hingelbaum S, Best R, Huth J, Wagner D, Bauer G, Mauch F (2014) The TT-TG Index: a new knee size adjusted measure method to determine the TT-TG distance. Knee Surg Sports Traumatol Arthrosc 22(10):2388–2395
14. Matsushita T, Kuroda R, Oka S, Matsumoto T, Takayama K, Kurosaka M (2014) Clinical outcomes of medial patellofemoral ligament reconstruction in patients with an increased tibial tuberosity-trochlear groove distance. Knee Surg Sports Traumatol Arthrosc 22(10):2438–2444
15. Nietosvaara Y, Aalto K, Kallio PE (1994) Acute patellar dislocation in children: incidence and associated osteochondral fractures. J Pediatr Orthop 14(4):513–515
16. Pandit S, Frampton C, Stoddart J, Lynskey T (2011) Magnetic resonance imaging assessment of tibial tuberosity-trochlear groove distance: normal values for males and females. Int Orthop 35(12):1799–1803
17. Seitlinger G, Scheurecker G, Hogler R, Labey L, Innocenti B, Hofmann S (2012) 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 40(5):1119–1125
18. Shrout PE, Fleiss JL (1979) Intraclass correlations: uses in assessing rater reliability. Psychol Bull 86(2):420–428
19. Smith TO, McNamara I, Donell ST (2013) The contemporary management of anterior knee pain and patellofemoral instability. Knee 20(suppl 1):S3–S15
20. Wilcox JJ, Snow BJ, Aoki SK, Hung M, Burks RT (2012) Does landmark selection affect the reliability of tibial tubercle-trochlear groove measurements using MRI? Clin Orthop Relat Res 470(8):2253–2260