Reliability of the Tibial Tubercle–Roman Arch Distance for Evaluating Tibial Tubercle Malposition and Predicting Patellar Dislocation via Magnetic Resonance Imaging

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Background: The tibial tubercle (TT)–trochlear groove (TT-TG) distance has low reproducibility in patients with a dysplastic trochlea, whereas the clinical value of the TT–posterior cruciate ligament (TT-PCL) distance remains controversial.

Purposes: To establish a method to assess the position of the TT on magnetic resonance imaging (MRI) scans using the TT–Roman arch (TT-RA) distance, compare this method with the TT-TG and TT-PCL distance, and provide the pathological threshold value of the TT-RA distance in patients with patellar dislocation.

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

Methods: The TT-RA distance, TT-TG distance, and TT-PCL distance were measured on MRI scans in 70 patients with a history of patellar dislocation and 70 healthy individuals. Inter- and intraobserver reliability of each measurement parameter were evaluated. The discriminatory capacity and the interrelationship of the 3 measurement parameters were investigated using Pearson correlation and the receiver operating characteristic curve. The pathological threshold values of these measurements were calculated according to the data of healthy individuals. Finally, logistic regression analysis was performed using these values.

Results: Patients with patellar dislocation had a greater TT-RA distance compared with healthy individuals (18.05 ± 4.16 vs 13.86 ± 2.90 mm; $P < .001$). The TT-RA distance had a stronger diagnostic capacity, with an area under the curve of 0.802 compared with 0.625 for TT-PCL distance. Excellent reproducibility was seen for TT-RA distance measurement at any degree of trochlear dysplasia (all intraclass correlation coefficients [ICCs] >0.90). The inter- and intraobserver ICCs of the TT-TG distance measurements were extremely low for Dejour type D dysplasia (ICC, 0.509 and 0.616, respectively). The pathological TT-RA distance threshold was calculated as 19.5 mm. Logistic regression showed that patients with a TT-RA distance >19.5 mm were 11.7 times more likely to sustain patellar dislocation than were those with TT-RA distance less than this value.

Conclusion: The TT-RA distance was a more reliable parameter with which to evaluate TT position than was TT-TG distance in patients with trochlear dysplasia. The TT-PCL distance was the least reliable among the 3 parameters studied.

Keywords: MRI; patellar dislocation; tibial tubercle osteotomy; TT-PCL distance; TT-RA distance; TT-TG distance

Medializing tibial tubercle (TT) osteotomy (TTO), in conjunction with medial patellofemoral ligament reconstruction, is a common surgical procedure used to correct abnormal tracking of the patella in patients with a TT–trochlear groove (TT-TG) distance of ≥ 20 mm.[13,33,34] The efficacy and validity of the TT-TG distance have been confirmed in numerous studies.[3,20,22,25] However, the measurement of this parameter in patients with trochlear dysplasia is less reproducible, especially in patients with high-grade trochlear dysplasia.[6,14,32] Moreover, the

TT-TG distance as measured on computed tomography (CT) scans is not equivalent to that on magnetic resonance imaging (MRI) scans, with a mean difference ranging from 2.2 to 4.16 mm.[1,3,22,23,26] In addition, the surgical cutoff value of TT-TG distance measured on MRI scans remains unknown, and the cutoff value may be influenced by patient age and body size. Although the TT–posterior cruciate ligament (TT-PCL) distance can supplement the deficiency of the TT-TG distance to some extent, the clinical value of the TT-PCL distance has not yet been fully validated.[1,6,8,22,32] These facts limit the clinical application of these imaging measurements.

Given the limitations of the TT-TG and TT-PCL distance measurements, we believe the highest point of the femoral
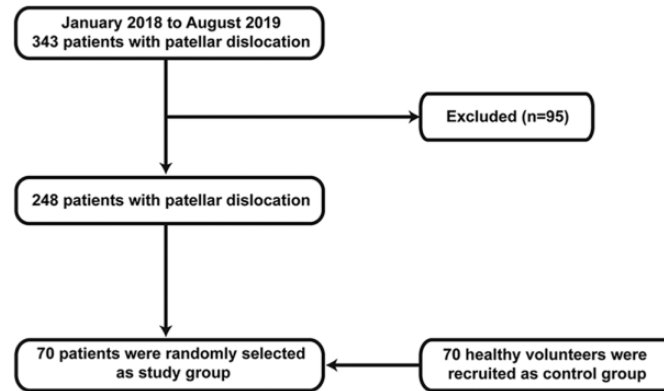
Figure 1. Flow diagram of patient allocation.

intercondylar notch (Roman arch [RA]) is a better landmark for the femur used to identify the relative position of the TT. In a previous study, we introduced the TT-RA distance. Although the TT-RA distance can be measured on CT scans, the radiation exposure is undesirable for young patients with patellar dislocation.[29] MRI examination can provide surgeons with a clearer visualization of soft tissue and cartilage, which is more suitable for patient evaluation and surgical plan formulation. However, the clinical practice value and reproducibility of TT-RA distance measured on MRI scans have not been validated.

The purposes of this study were to establish a method to assess the TT-RA distance on MRI scans, compare the TT-RA distance measurements with those for the TT-TG and TT-PCL, and provide the pathological threshold value of the TT-RA distance in patients with patellar dislocation. We hypothesized that the TT-RA distance would have high reproducibility on MRI scans and show better clinical practice value compared with the other distance parameters in evaluating patellar dislocation.

METHODS

Between January 2018 and August 2019, a total of 343 consecutive patients diagnosed with recurrent patellar dislocation underwent surgical treatment in our department. Patients with the following criteria were excluded: (1) a significant ligamentous knee injury (n = 6); (2) without necessary clinical, operative, or radiological data (n = 45);

(3) previous fracture or surgery of the lower limb (n = 32); and (4) bilateral patellar dislocation (n = 12). After the application of exclusion criteria, there were 248 patients eligible. These patients were sorted according to their surgery date, and the first 35 patients with surgery on the left knee and the first 35 patients with surgery on the right knee were selected as the study group. At the same time, 70 healthy volunteers of similar ages and with no history of lower extremity pain or injury were recruited as the control group (Figure 1). The study protocol received ethics committee approval, and informed consent was obtained from every participant.

An orthopaedic surgeon (H.W.) from our department performed medical history inquiries and physical examinations with the volunteers to ensure the eligibility of the study participants. Detailed information was obtained from the medical records for patients with patellar dislocation.

MRI Technique

The MRI examinations were performed within 1 week preoperatively. All examinations were performed using the same 1.5-T MRI scanner (Signa; GE Healthcare). The axial plane of the knee joint was scanned using a T1-weighted turbo spin-echo (TSE) sequence and a proton density TSE with fat-suppressed sequence. The patients were positioned in the supine position. The target knee was placed in the multichannel knee phased array coil, the leg was placed straightened, and the toes were positioned

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Figure 2. Method of measuring the TT-RA distance on the right knee. (A) The RA is defined as a line perpendicular to the PCRL that passes through the tangent point of the RA. (B) The landmark of the TT of TT-RA distance measurements: the center of the patellar tendon with total attachment to the TT. PCRL, posterior condylar reference line; RA, Roman arch; TLRA, tangent line of RA; TT, tibial tubercle.
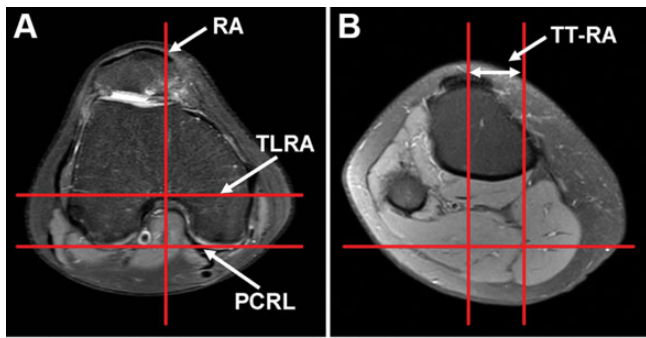

Figure 3. Method of measuring the TT-TG distance on the right knee. (A) The TG is defined as a line perpendicular to the PCRL that passes through the deepest portion of the TG. (B) The landmark of the TT of the TT-TG distance: the center of the patellar tendon with total attachment to the TT. PCRL, posterior condylar reference line; TG, trochlear groove; TT, tibial tubercle.

upward. Sandbags or cushions were used to maintain the knee position. The scan range was centered on the tibia and included the entire knee joint. Routine scans of the coronal and sagittal planes were performed using proton density TSE with fat-suppressed sequence. The layer thickness was set to 3.5 mm, the slice gap was 0.5 mm, the field of view was 160 mm, and the matrix was 512 × 512.

TT-RA Distance

We modified the method of measuring TT-RA distance as previously described for CT.[29] We used the center of the patellar tendon to locate the TT. The TT-RA distance on MRI scans was defined as the distance between the center of the patellar tendon with total attachment to the TT and the highest point of the RA. The reference slice of the RA was defined as the most proximal slice that showed the intact intercondylar notch and posterior femoral condyle. The posterior condylar reference line was drawn tangent to the posterior femoral condyles, and a line parallel to the posterior condylar reference line was drawn passing through the tangent point of the RA. This point was defined as the landmark of the RA. The landmark of the TT was the center of the patellar tendon with total attachment to the TT on the most proximal MRI slice. The TT-RA distance was defined as the distance between the 2 parallel lines through the landmark of the TT and the RA (Figure 2).

TT-TG Distance

The measurement of TT-TG distance on MRI scans was performed in accordance with the Camp method.[2] The most proximal slice that depicted complete cartilaginous trochlear and posterior condyles was used to define the deepest point of the TG. The first craniocaudal image showing a complete patellar tendon attachment on the TT was used to determine the center of the patellar tendon. The TT-TG
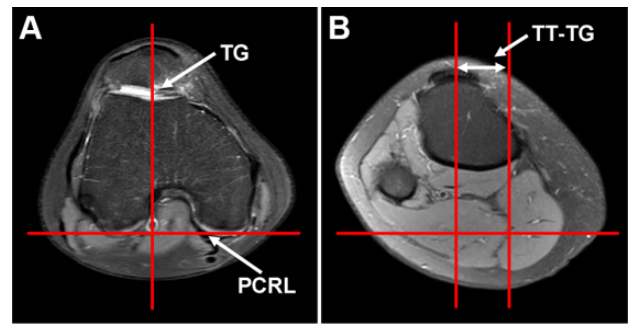
distance was defined as the distance between the 2 parallel lines via the midpoint of the patellar tendon and the deepest point of the TG (Figure 3).

TT-PCL Distance

We measured TT-PCL distance according to the method used by Seitlinger et al.[19] The TT-PCL was defined as the distance between the midpoint of the patellar tendon with total attachment to the TT and the medial border of the PCL. The measurement of this distance was parallel to the dorsal condylar line. The reference slice of the PCL was defined in the most distal slice that showed this ligament clearly. The reference slice of the dorsal condylar line was defined in the slice just below the articular surface of the tibial plateau and above the fibular head. The landmark of the TT was the center of the patellar tendon with total attachment to the TT on the most proximal MRI slice. The distance of 2 parallel lines through the patellar tendon and PCL perpendicular to the dorsal condylar line was defined as the TT-PCL distance (Figure 4).

Trochlear Morphology

The most proximal image with the entire width of the trochlea on the axial MRI scans was selected for evaluation.[16] Trochlear morphology was classified according to the Dejour classification as types A through D.[4] The 2-type trochlear dysplasia classification of low grade (type A) and high grade (types B, C, and D) was also applied to present the results.[24]

Intra- and Interobserver Reliability

Two orthopaedic surgeons (Z.X. and P.Z.) with >10 years of experience performed all the measurements. All measurements were performed simultaneously in
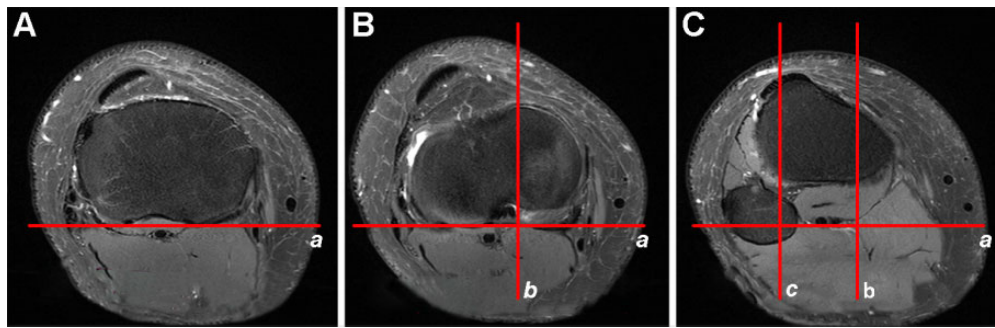
Figure 4. Method of measuring the tibial tubercle–posterior cruciate ligament (TT-PCL) distance. (A) Line *a* is the tangent line of the dorsal condylar line. (B) Line *b* is a line vertical to line *a* and passes through the medial border of the PCL. (C) Line *c* is parallel to line *b* and passes through the medial point of the patellar tendon. The distance between lines *b* and *c* is the TT-PCL distance.

a blind and randomized fashion to determine inter-observer reliability. The senior orthopaedic surgeon (P.Z.) re-examined all the measurements after 6 weeks to evaluate intraobserver reliability. The average values measured by 2 observers (Z.X. and P.Z.) were used for comparison.

The intraclass correlation coefficient (ICC) was calculated for each measurement parameter, with an ICC of >0.75 indicating excellent agreement.[27,28,32] In addition, we analyzed the reliability of the measurements for each parameter by degree of trochlear dysplasia.

Statistical Analysis

For statistical analysis, all data were entered into SPSS software (Version 21.0; IBM, Armonk, NY) and MedCalc software (Version 19.0.7; Ostend, Belgium). The Shapiro-Wilk normality test was performed to confirm the distribution of the data. The *t* test or Mann-Whitney *U* test was applied to compare the difference between the study and control groups according to data distribution. The reproducibility of each measurement parameter was assessed using the ICC, in which ICC >0.75 indicated excellent agreement. Pearson correlation analysis was performed to evaluate the interrelationship between the 3 measurement parameters.

The data of the study and control participants were input into the MedCalc software for receiver operating characteristic (ROC) analysis. The cutoff value for predicting patellar dislocation with sensitivity and specificity was calculated using MedCalc software. For parameters with an area under the ROC (AUC) >0.80, the cutoff value of the parameters with sensitivity and specificity were recorded. The pathological threshold values of the included parameters were determined via the 95% CI based on data from healthy volunteers.[5,19] The logistic regression was performed using the cutoff values and pathological threshold values of included parameters. The odds ratio at each value was calculated for the TT-RA distance, TT-TG distance, and TT-PCL distance.

Power analysis using G Power software (Version 3.0; Heinrich-Heine-Universitat Dusseldorf, Dusseldorf, Germany) was performed. A previous power analysis based on

TABLE 1
Characteristics of the Study Patients[a]

Variable	Study Group (n = 70)	Control Group (n = 70)	P
Age, y, mean ± SD	22.6 ± 7.6	24.6 ± 6.5	.88
Sex, n			.59
Female	47	35	
Male	23	35	
Side of the knee joint, n			>.99
Left	35	35	
Right	35	35	
Trochlear dysplasia, n			**<.001**
Normal	17	46	
Type A	20	23	
Type B	22	1	
Type C	7	0	
Type D	4	0	
High-grade dysplasia, n[b]	33	1	

[a]Boldface *P* value indicates statistically significant difference between groups (*P* < .05).
[b]Type B, type C, and type D trochlear dysplasia.

an effect size of 0.8 determined a sample size of 70 patients was needed. It was estimated that at least 35 patients in each group were adequate to detect significant differences with a power of 95% and an α = .05.

RESULTS

Patients in the study group had a mean age of 22.6 years, and patients in the control group had a mean age of 24.6 years. There were 23 male (32.9%) and 47 female (67.1%) patients in the study group and 35 male (50%) and 35 female (50%) participants in the control group. The detailed descriptive data of the included participants are shown in Table 1.

The mean and standard deviation measurement values are presented in Figure 5. Significantly greater values were found in the study group compared with the control group regarding TT-RA distance (18.1 ± 4.2 vs 13.9 ± 2.9 mm
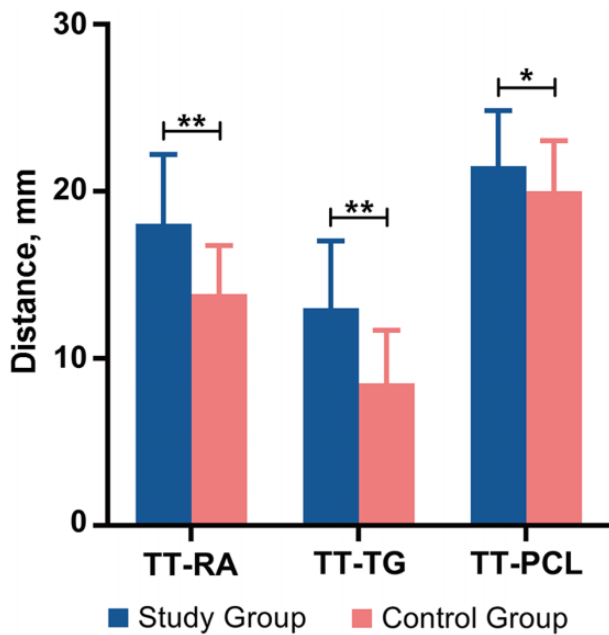
Figure 5. The mean ± SD differences in TT-PCL, TT-RA, and TT-TG measurements between the study group and the control group. Statistically significant difference between groups: *P < .05; **P < .001. PCL, posterior cruciate ligament; RA, Roman arch; TG, trochlear groove; TT, tibial tubercle.

TABLE 2
Inter- and Intraobserver Reliability of Measurements[a]

Measurement Parameter	ICC (95% CI)	
	Interobserver	Intraobserver
TT-RA distance	0.968 (0.956-0.977)	0.973 (0.962-0.981)
TT-TG distance	0.927 (0.898-0.947)	0.929 (0.901-0.949)
TT-PCL distance	0.925 (0.895-0.946)	0.963 (0.948-0.973)

[a]An ICC >0.75 indicated excellent agreement. ICC, intraclass correlation coefficient; PCL, posterior cruciate ligament; RA, Roman arch; TG, trochlear groove; TT, tibial tubercle.

[P < .001]; mean difference, 4.2 mm), TT-TG distance (13.0 ± 4.0 vs 8.5 ± 3.2 mm [P < .001]; mean difference, 4.5 mm), and TT-PCL distance (21.5 ± 3.3 vs 20.0 ± 3.0 mm [P = .006]; mean difference, 1.5 mm).

Excellent inter- and intraobserver reliability was found regarding all included measurements (ICC >0.92 for all). Both the TT-TG and TT-PCL distance measurements had relatively lower inter- and intraobserver reliability compared with those for TT-RA distance (Table 2).

When analyzed according to degree of trochlear dysplasia, the inter- and intraobserver reliability were excellent for all classification types with respect to TT-RA distance measurements (ICC, >0.941 and >0.900, respectively) and TT-PCL distance measurements (ICC, >0.833 and >0.900, respectively). As the severity of trochlear dysplasia increased, the reliability of the TT-TG distance measurements decreased and was very low in type C (ICC, 0.794 and 0.799, respectively) and type D (ICC, 0.509 and 0.616, respectively) compared with the TT-RA and TT-PCL measurements (Figure 6).

A total of 63 participants (17 participants in the study group and 46 participants in the control group had normal femoral trochlea, see Table 1) without trochlear dysplasia were included in a subgroup to evaluate the interrelationship between the measurement parameters. The mean TT-RA distance, TT-TG distance, and TT-PCL distance in this subgroup were 14.7, 9.4, and 19.9 mm, respectively. Pearson correlation analysis showed a strong correlation between TT-TG and TT-RA distance ($r = 0.851$; $P < .001$), a weak correlation between TT-TG and TT-PCL distance ($r = 0.366$; $P = .03$), and a weak correlation between TT-RA and TT-PCL distance ($r = 0.396$; $P = .01$) (Figure 7).

In addition, the capacity of the 3 measurement parameters to predict patellar dislocation was evaluated using ROC analyses. The results showed that TT-TG distance and TT-RA distance had almost identical diagnostic capacity, with AUCs of 0.818 and 0.802, respectively. However, the TT-PCL distance had an AUC value of only 0.625. At a TT-RA distance of >15.6 mm, the sensitivity and specificity for predicting patellar dislocation were 74.3% and 78.6%, respectively; at a TT-TG distance of >11.0 mm, the sensitivity and specificity were 65.7% and 82.9%, respectively; and at a TT-PCL distance of >20.7 mm, the sensitivity and specificity were 61.43% and 61.43%, respectively (Figure 8).

All of the included measurements were distributed normally based on the Shapiro-Wilk test. The physiological ranges and pathological threshold values for the TT-RA, TT-TG, and TT-PCL distances are presented in Table 3. According to the data of healthy individuals, the pathological threshold values for the TT-RA, TT-TG, and TT-PCL distances were 19.5, 14.8, and 25.9 mm, respectively, and 95% of healthy individuals had these threshold values within their physiological range. In the study group, 34.29% (24 of 70) of the patients had excessive TT-RA distance, 31.43% (22 of 70) patients had excessive TT-TG distance, and 8.6% (6 of 70) patients had abnormal TT-PCL distance.

Logistic regression was performed using the cutoff values obtained using the ROC curve and the pathological threshold values to determine the independent risk factors for the incidence of patellar dislocation (Figure 9). The results showed that the threshold values calculated using the data of healthy individuals, not the ROC curve, had a stronger capacity to predict patellar dislocation. TT-RA distance had the strongest capacity to predict patellar dislocation. Healthy individuals with a TT-RA distance of >19.5 mm had an 11.652-fold higher risk of patellar dislocation than did those with values <19.5 mm (P < .001).

DISCUSSION

This study is the first to establish the method of TT-RA distance measurement on MRI scans and to validate the clinical implication by comparing this parameter with other methods of assessing TT lateralization (TT-TG distance
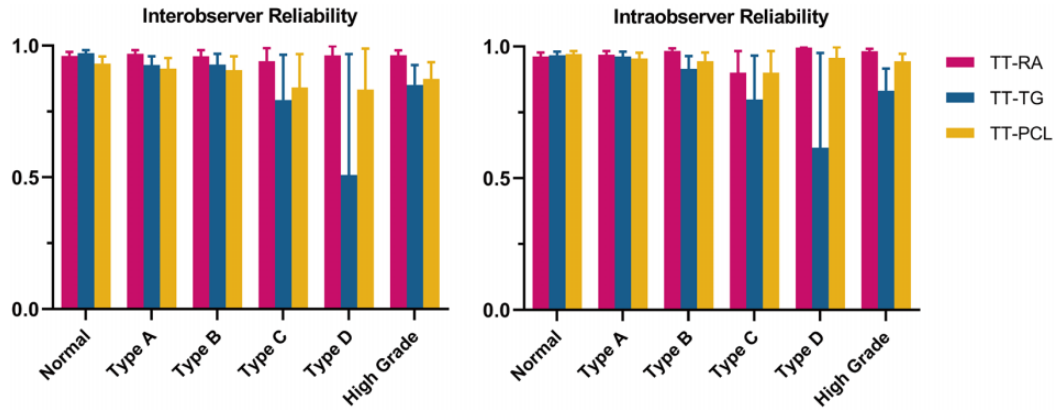
Figure 6. Interobserver and intraobserver reliability of included TT-PCL, TT-RA, and TT-TG measurements according to trochlear morphology classification. High grade = type B, type C, and type D. PCL, posterior cruciate ligament; RA, Roman arch; TG, trochlear groove; TT, tibial tubercle.
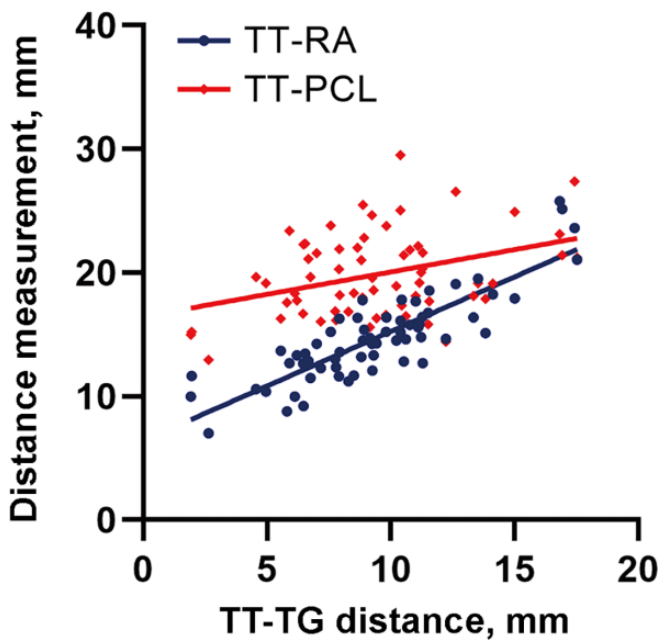

Figure 7. Correlations between each TT-PCL, TT-RA, and TT-TG measurement parameter. PCL, posterior cruciate ligament; RA, Roman arch; TG, trochlear groove; TT, tibial tubercle.

and TT-PCL distance). The most important findings of this study are as follows: (1) the TT-RA distance was confirmed to be a reliable parameter used to evaluate TT position and had a stronger ability to predict patellar dislocation than did the TT-TG distance in patients with patellar dislocation, especially in those with trochlear dysplasia. (2) The pathological threshold value of TT-RA distance was 19.5 mm. (3) There was an interrelationship between TT-TG and TT-RA distances in patients with normal trochlear morphology. These findings suggest that TT-RA distance has a wider clinical application value than do TT-TG and TT-PCL distances.

Seitlinger et al[19] introduced the TT-PCL distance as a parameter to define the position of the TT in patients with patellar dislocation. They considered a TT-PCL distance of <24 mm as within the normal range, but they did not provide the cutoff value needed for surgical intervention. Their study showed that the correlation between TT-PCL distance and TT-TG distance was low ($R^2 = 0.34$). Compared with their study, the data from the current study showed the TT-RA distance had a strong correlation with TT-TG distance ($r = 0.851$).

A TT-TG distance of at least 20 mm has been used widely as an indicator for TTO surgery.[5,7,21,31,34] However, the measurement of TT-TG distance has poor reproducibility in patients with trochlear dysplasia, especially in high-grade trochlear dysplasia.[6,12,14] Dejour et al[5] reported that 96% of patients with patellar dislocation had trochlear dysplasia. A recent study showed that the interobserver ICC for TT-TG distance was 0.64 for Dejour type D dysplasia.[14] Another study reported an interobserver agreement for TT-TG distance of <60% in patients with severe trochlear dysplasia.[18] In the current study, we found that the ICC values of TT-RA distance and TT-PCL distance were higher than that for TT-TG distance in patients with trochlear dysplasia. The low ICC values of TT-TG distance in patients with a high-grade dysplastic trochlea (inter- and intraobserver ICC, 0.509 and 0.616 for type D) in our study are in accordance with those of previous studies.[6,12,14]

Previous studies have evaluated the TT-TG distance on MRI scans as a convenient means of assessing ligaments and cartilage.[9,32] Since the measurement of TT-TG distance is easily influenced by the knee flexion angle, the measured value is not equivalent between CT and MRI scans in the same patient.[3,20,23] Therefore, the cutoff value of TT-TG distance of at least 20 mm as measured on MRI scans cannot be applied as the surgical indication of TTO.[32] Recent studies have not been able to establish the pathological TT-TG value on MRI scans that can be used to indicate TTO surgery.[11,17] The mean value and pathological threshold of the TT-RA distance as measured on MRI scans in the current study also differed from those measured on CT scans.[29]
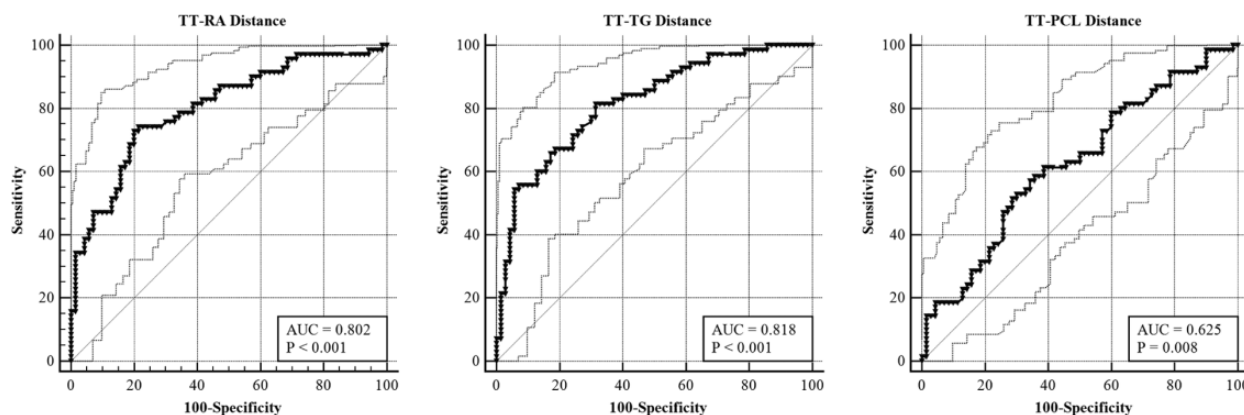
Figure 8. The ROC curve of included TT-PCL, TT-RA, and TT-TG parameters. AUC, area under the ROC curve; PCL, posterior cruciate ligament; RA, Roman arch; ROC, receiver operating characteristic; TG, trochlear groove; TT, tibial tubercle.

TABLE 3
Pathological Threshold Values and Physiological Ranges of the TT-RA, TT-TG, and TT-PCL Distances[a]

Measurement Parameter	Physiological Range, mm	Pathological Threshold Value, mm
TT-RA distance	8.2-19.5	19.5
TT-TG distance	2.2-14.8	14.8
TT-PCL distance	14.1-25.9	25.9

[a]PCL, posterior cruciate ligament; RA, Roman arch; TG, trochlear groove; TT, tibial tubercle.
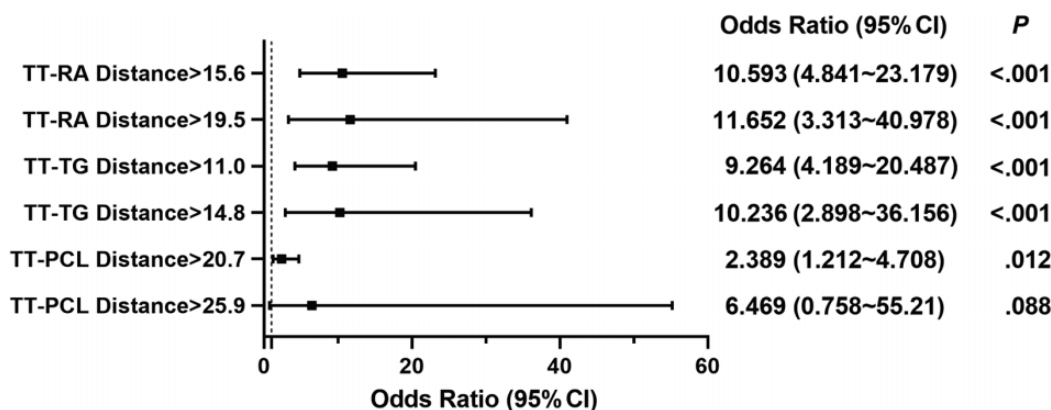

Figure 9. Binary logistic regression analysis to evaluate independent risk factors for patellar dislocation incidence. PCL, posterior cruciate ligament; RA, Roman arch; TG, trochlear groove; TT, tibial tubercle.

In the current study, the value of TT-RA distance in diagnosing patellar dislocation (AUC = 0.802) was higher than that of the TT-PCL distance (AUC = 0.625) and no less than that of the TT-TG distance (AUC = 0.818). Although the difference in AUC between TT-RA distance and TT-TG distance was small (0.016), the almost perfect reproducibility of the TT-RA distance measurements (interobserver ICC, 0.968; intraobserver ICC, 0.973) make this parameter superior to the other 2 parameters.

The method of defining the pathological threshold value of TT-RA distance was in accordance with the method used to define the pathological threshold values of TT-TG

distance and TT-PCL distance.[5,19] In addition, we recruited healthy individuals as the control group so our results would be less potentially biased compared with those of other studies that included patients with anterior cruciate ligament injury or patients without patellofemoral disease as the control group.[10,14,15,30] With the data from our 70 healthy volunteers, we calculated a pathological threshold value for the TT-RA distance of 19.5 mm, which was based on the 95% CI. This threshold value can help the surgeon formulate a surgical plan, as a postoperative tibial tubercle position greater than this value indicates a failure to restore normal anatomy.

The results of the logistic regression determined that patients have the highest risk of patellar dislocation when their TT-RA distance is >19.5 mm (OR = 11.652; P < .001) (Figure 9). This result suggests that a TT-RA distance of >19.5 mm may be the most suitable value to indicate the TTO procedure, as patients with postoperative TT-RA distance >19.5 mm are more likely to sustain patellar dislocation. However, this hypothesis needs to be further validated.

The strong correlation between TT-TG distance and TT-RA distance indicated that the tangent point of RA could be substituted for the TG as a reference point for TT position evaluation. The positional relationship between RA and TG also can be applied in the trochleoplasty procedure. This finding also can assist in locating the appropriate site to deepen the femoral trochlea during the trochleoplasty procedure.

Limitations

Our study has some limitations. First, the number of patients with high-grade trochlear dysplasia, especially patients with types C and D trochlear dysplasia, was not large enough to show the strength of TT-RA distance measurement. Second, the postoperative outcomes of the TTO procedure using these pathological threshold values still need to be investigated further. Third, it may be difficult to classify trochlear dysplasia on axial MRI scans in some cases, although in these instances, trochlear morphology could be assessed using radiography. Fourth, although the aim was to have the knee extended in the MRI scanner, the actual knee angle was not measured.

CONCLUSION

The study findings indicated that the TT-RA distance is more reliable to evaluate TT position than is the TT-TG distance in patients with trochlear dysplasia. Both techniques can be used in combination for more accuracy in patients with or without minor trochlear dysplasia. The TT-PCL distance was the least reliable among the 3 measurement parameters studied.

REFERENCES

1. Anley CM, Morris GV, Saithna A, James SL, Snow M. Defining the role of the tibial tubercle–trochlear groove and tibial tubercle–posterior cruciate ligament distances in the work-up of patients with patellofemoral disorders. *Am J Sports Med*. 2015;43(6):1348-1353.
2. Camp CL, Stuart MJ, Krych AJ, et al. CT and MRI measurements of tibial tubercle–trochlear groove distances are not equivalent in patients with patellar instability. *Am J Sports Med*. 2013;41(8): 1835-1840.
3. Dai ZZ, Sha L, Zhang ZM, et al. Comparing the tibial tuberosity–trochlear groove distance between CT and MRI in skeletally immature patients with and without patellar instability. *Orthop J Sports Med*. 2021;9(1):2325967120973665.
4. Dejour D, Le Coultre B. Osteotomies in patello-femoral instabilities. *Sports Med Arthrosc Rev*. 2018;26(1):8-15.

5. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc*. 1994;2(1):19-26.
6. Dong C, Zhao C, Li M, et al. Accuracy of tibial tuberosity-trochlear groove distance and tibial tuberosity-posterior cruciate ligament distance in terms of the severity of trochlear dysplasia. *J Orthop Surg Res*. 2021;16(1):383.
7. Franciozi CE, Ambra LF, Albertoni LJB, et al. Anteromedial tibial tubercle osteotomy improves results of medial patellofemoral ligament reconstruction for recurrent patellar instability in patients with tibial tuberosity–trochlear groove distance of 17 to 20 mm. *Arthroscopy*. 2019;35(2):566-574.
8. Friedman MV, Hillen TJ, Misra S, Hildebolt CF, Rubin DA. Quantitative variable assessment of patellar instability: an MRI-based study. *AJR Am J Roentgenol*. 2020;215(5):1163-1170.
9. Frings J, Dust T, Krause M, et al. Objective assessment of patellar maltracking with 3T dynamic magnetic resonance imaging: feasibility of a robust and reliable measuring technique. *Sci Rep*. 2020;10(1): 16770.
10. Ikuta Y, Ishikawa M, Suga N, et al. New standardization method of tibial tubercle-posterior cruciate ligament distance according to patient size in patients with patellofemoral instability. *Knee*. 2020; 27(3):695-700.
11. Imhoff FB, Funke V, Muench LN, et al. The complexity of bony malalignment in patellofemoral disorders: femoral and tibial torsion, trochlear dysplasia, TT-TG distance, and frontal mechanical axis correlate with each other. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(3): 897-904.
12. Keehan R, Gill A, Smith L, Ahmad R, Eldridge J. Mid inter-epicondyle trochlea intersection (MIELTI): proposal of a new index for identifying the deepest part of the trochlea. *Knee*. 2019;26(6):1204-1209.
13. Leite CBG, Santos TP, Giglio PN, et al. Tibial tubercle osteotomy with distalization is a safe and effective procedure for patients with patella alta and patellar instability. *Orthop J Sports Med*. 2021;9(1): 2325967120975101.
14. Nha K, Nam YJ, Shin MJ, et al. Referencing the trochlear groove based on three-dimensional computed tomography imaging improves the reliability of the measurement of the tibial tuberosity–trochlear groove distance in patients with higher grades of trochlea dysplasia. *Knee*. 2019;26(6):1429-1436.
15. Nizić D, Šimunović M, Pavliša G, Jelić M. Tibial tuberosity–tibial intercondylar midpoint distance measured on computed tomography scanner is not biased during knee rotation and could be clinically more relevant than current measurement systems. *Int Orthop*. 2021; 45(4):959-970.
16. Otto A, Tscholl PM, Pääsuke R, et al. Neither lateral patellar facet nor patellar size are altered in patellofemoral unstable patients: a comparative magnetic resonance imaging analysis. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(4):1064-1071.
17. Paiva M, Blønd L, Hölmich P, Barfod KW. Effect of medialization of the trochlear groove and lateralization of the tibial tubercle on TT-TG distance: a cross-sectional study of dysplastic and nondysplastic knees. *Am J Sports Med*. 2021;49(4):970-974.
18. Saudan M, Fritschy D. AT-TG (anterior tuberosity-trochlear groove): interobserver variability in CT measurements in subjects with patellar instability. Article in French. *Rev Chir Orthop Reparatrice Appar Mot*. 2000;86(3):250-255.
19. Seitlinger G, Scheurecker G, Hogler R, et al. Tibial tubercle–posterior cruciate ligament distance: a new measurement to define the position of the tibial tubercle in patients with patellar dislocation. *Am J Sports Med*. 2012;40(5):1119-1125.
20. Shu L, Ni Q, Yang X, et al. Comparative study of the tibial tubercle-trochlear groove distance measured in two ways and tibial tubercle-posterior cruciate ligament distance in patients with patellofemoral instability. *J Orthop Surg Res*. 2020;15(1):209.
21. Song YF, Wang HJ, Yan X, et al. Tibial tubercle osteotomy may not provide additional benefit in treating patellar dislocation with increased tibial tuberosity–trochlear groove distance: a systematic review. *Arthroscopy*. 2021;37(5):1670-1679.e1671.

22. Su P, Jian N, Mao B, et al. Defining the role of TT-TG and TT-PCL in the diagnosis of lateralization of the tibial tubercle in recurrent patellar dislocation. *BMC Musculoskelet Disord*. 2021;22(1):52.

23. Tan SHS, Lim BY, Chng KSJ, et al. The difference between computed tomography and magnetic resonance imaging measurements of tibial tubercle–trochlear groove distance for patients with or without patellofemoral instability: a systematic review and meta-analysis. *J Knee Surg*. 2020;33(8):768-776.

24. Tscholl PM, Wanivenhaus F, Fucentese SF. Conventional radiographs and magnetic resonance imaging for the analysis of trochlear dysplasia: the influence of selected levels on magnetic resonance imaging. *Am J Sports Med*. 2017;45(5):1059-1065.

25. Vairo GL, Moya-Angeler J, Siorta MA, Anderson AH, Sherbondy PS. Tibial tubercle-trochlear groove distance is a reliable and accurate indicator of patellofemoral instability. *Clin Orthop Relat Res*. 2019; 477(6):1450-1458.

26. van Huyssteen AL, Hendrix MR, Barnett AJ, Wakeley CJ, Eldridge JD. Cartilage-bone mismatch in the dysplastic trochlea: an MRI study. *J Bone Joint Surg Br*. 2006;88(5):688-691.

27. Weltsch D, Chan CT, Mistovich RJ, et al. Predicting risk of recurrent patellofemoral instability with measurements of extensor mechanism containment. *Am J Sports Med*. 2021;49(3):706-712.

28. Xu Z, Zhang H, Chen J, Mohamed SI, Zhou A. Femoral anteversion is related to tibial tubercle-trochlear groove distance in patients with patellar dislocation. *Arthroscopy*. 2020;36(4):1114-1120.

29. Xu Z, Zhang H, Fu B, et al. Tibial tubercle–Roman arch distance: a new measurement of patellar dislocation and indication of tibial tubercle osteotomy. *Orthop J Sports Med*. 2020;8(4):2325967120914872.

30. Xu Z, Zhang H, Guo M, et al. Malalignment sign on knee magnetic resonance imaging: a new predictor for excessive femoral anteversion in patients with patellar dislocation. *Knee Surg Sports Traumatol Arthrosc*. 2021;29(4):1075-1082.

31. Xu Z, Zhang H, Yan W, Chen J, Zhou A. How to evaluate and treat skeletally mature patients with patellar dislocation. *Arthrosc Tech*. 2021;10(3):e721-e726.

32. Xu Z, Zhang H, Yan W, et al. Validating the role of tibial tubercle–posterior cruciate ligament distance and tibial tubercle–trochlear groove distance measured by magnetic resonance imaging in patients with patellar dislocation: a diagnostic study. *Arthroscopy*. 2021;37(1):234-242.

33. Zhang Z, Song G, Ni Q, et al. Preoperative complete patellofemoral dislocation in extension predicts an inferior clinical outcome after medial patellofemoral ligament reconstruction in patients with recurrent patellar dislocation. *Orthop J Sports Med*. 2020;8(7):2325967 120938981.

34. Zhang Z, Zhang H, Song G, et al. Increased femoral anteversion is associated with inferior clinical outcomes after MPFL reconstruction and combined tibial tubercle osteotomy for the treatment of recurrent patellar instability. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(7): 2261-2269.