

Tibial Tubercle–Roman Arch Distance

A New Measurement of Patellar Dislocation and Indication of Tibial Tubercle Osteotomy

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Background: The surgical indication for tibial tubercle osteotomy (TTO) has been based on a tibial tubercle–trochlear groove (TT-TG) distance of 20 mm or greater in patients with patellar dislocation. However, the measurement of this parameter is less reliable in patients with trochlear dysplasia.

Hypothesis: The novel measurement of tibial tubercle–Roman arch (TT-RA) distance would be a reliable parameter for identifying the relative position of the tibial tubercle in patients with patellar dislocation, especially those with trochlear dysplasia.

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

Methods: A total of 56 patients with a diagnosis of patellar dislocation and 60 volunteers (60 knee joints) without a history of lower extremity pain or injury were included in our study. The TT-RA distance, TT-TG distance, and some femoral anatomic parameters were assessed by use of computed tomography. The measurements were performed by a radiologist and an orthopaedic surgeon in a blinded and randomized fashion. The difference in each parameter between the study and control groups was analyzed through use of an unpaired *t* test. Receiver operating characteristic curve analysis was performed to evaluate the discriminatory capacity of the included parameters. The cutoff values of the included measurements with specificity and sensitivity were calculated. In addition, the TT-TG distance and TT-RA distance were analyzed using the Dejour classification to evaluate the intraclass correlation coefficient (ICC) of each parameter in different types of femoral trochlea.

Result: A significant difference for TT-RA distance was found between the study group (23.24 ± 4.41 mm) and control group (19.15 ± 4.24 mm) ($P < .001$). The TT-RA distance had an area under the curve of 0.757. At a value greater than 23.74 mm, TT-RA distance had 53.57% sensitivity and 88.33% specificity for patellar dislocation. The ICCs of TT-RA distance measurements were excellent in all Dejour classifications (>0.939), whereas the ICCs of TT-TG distance measurements were relatively lower than the ICCs of TT-RA distance measurements. According to the data from included healthy individuals, the pathological TT-RA distance threshold was 26 mm.

Conclusion: Compared with TT-TG distance, the TT-RA distance is a more reliable parameter for identifying the relative position of the tibial tubercle in patients with trochlear dysplasia. For patients with a TT-RA distance greater than 26 mm, surgery should be considered to correct the malposition of the tibial tubercle.

Keywords: patellar dislocation; tibial tubercle–Roman arch distance; tibial tubercle osteotomy; tibial tubercle–trochlear groove distance

Patellar dislocation is a common knee disorder seen in young adults, especially women.^{2,5,21,30} Patellar dislocation can lead to combined complications such as osteochondral fracture and patellofemoral arthritis.^{11,25} Tibial tubercle osteotomy (TTO) is a common surgical procedure used to correct abnormal patellar tracking caused by the

lateral force vector. It has been reported that excessive lateral force in patients with patellar dislocation was the main cause of the lateralization of the tibial tubercle and other rotational deformities.²³ Therefore, the TTO procedure is performed to balance this excessive lateral force.

The surgical indication for TTO has been a tibial tubercle–trochlear groove (TT-TG) distance of 20 mm or more, which was proposed by Dejour et al¹⁴ in 1994 and has been the standard indication for TTO surgery. Dejour et al proposed that for patients with patellar dislocation,

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medialization of the tibial tubercle should be performed when the distance between the most anterior portion of the bony tibial tubercle and the deepest portion of the trochlear groove is greater than 20 mm to correct the excessive lateralization of the tibial tubercle.¹⁴ However, it is difficult to define the deepest point of the trochlear groove for patients with trochlear dysplasia.^{10,22} In a previous study, patients with type C or type D trochlea (according to the Dejour classification) were reported to have less than 60% interobserver agreement for TT-TG distance measurement.²⁶ That study showed lower reliability of the TT-TG distance in patients with trochlear dysplasia. However, most patients with patellar dislocation have a combination of different degrees of trochlear dysplasia.¹⁴

Given the limitations of the measurement of TT-TG distance, we think that the Roman arch may be a better femoral landmark to identify the relative position of the tibial tubercle. In this study, we introduce a new measurement—the tibial tubercle–Roman arch (TT-RA) distance—obtained via computed tomography (CT). The distance between the highest point of the Roman arch and the center of the tibial tubercle with the patellar tendon completely in contact was used to assess the lateralization of the tibial tubercle in patients with trochlear dysplasia.

The purpose of this study was to establish a novel parameter to assess the relative position of the tibial tubercle and provide an indication for TTO surgery in patients with patellar dislocation, even if they have different degrees of trochlea dysplasia.

METHODS

Study Population

After approval was obtained from the ethics committee of our hospital, images of patients were retrospectively collected. The departmental electronic medical record system was searched for patients diagnosed with patellar dislocation between 2016 and 2019. The inclusion criteria were patients with a history of patellar dislocation or those with a clinical and radiological diagnosis of patellar dislocation who had been indicated for surgery. Patients with previous knee surgeries, with previous fractures involving the knee, or without appropriate radiological examinations were excluded. A total of 56 patients were included in our study. Of these patients, 15 (27%) had a first-time dislocation and 41 (73%) had recurrent dislocations. Further, 15 (27%) patients were male and 41 (73%) were female. A total of 60 volunteers (60 knee joints) without a history

of lower extremity pain or injury were recruited as a control group.

Informed consent was obtained from every member of the control group. The medical history inquiry and physical examinations of the volunteers were performed by an orthopaedic surgeon from our department (H.Z.) to ensure suitability for the study. For patients with patellar dislocation, detailed information about the patients, the mechanism of injury, and the indication for CT examinations were obtained from the medical records or retrospective telephone interview.

CT Technique

Images were obtained with a CT scanner (Siemens Somatom Perspective). All patients underwent examination in the supine position with the knee at full extension and the foot in a neutral position. The scan range for the study group was from the anterosuperior iliac spine to the tip of the toes, whereas the scan range for the control group was from 5 cm above the distal femur to 5 cm below the tibial plateau. The scanning parameters were as follows: tube voltage, 130 kVp; tube current, 110 to 140 mA; scanning layer thickness and layer spacing, 5 mm; and matrix, 512 × 512 pixels. The field of view varied according to the size of the knee joint, ranging from 220 to 450 mm.

Measurement of Parameters

The CT data were imported into Adobe Photoshop CS6 (Adobe Inc) for measurement of parameters. All measurements were performed simultaneously by a radiologist and an orthopaedic surgeon (B.F., H.Z.) in a blinded and randomized fashion. The values measured by the 2 observers were averaged for comparison.

TT-RA Distance

The TT-RA distance was determined by the distance between the center of the tibial tubercle, with the patellar tendon completely in contact, and the highest point of the Roman arch. The reference slice of the Roman arch was the most proximal CT slice that would allow visualization of the intact Roman arch and posterior femoral condyles. The posterior condylar reference line (PCRL) was drawn tangent to the posterior femoral condyles. The tangent line of the Roman arch was defined as a line parallel to the PCRL, passing through the tangent point of the Roman arch. This tangent point was considered the bony landmark of the Roman arch. The bony landmark of the tibial tubercle was

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Ethical approval for this study was obtained from the First Affiliated Hospital of Chongqing Medical University, Chongqing, China.

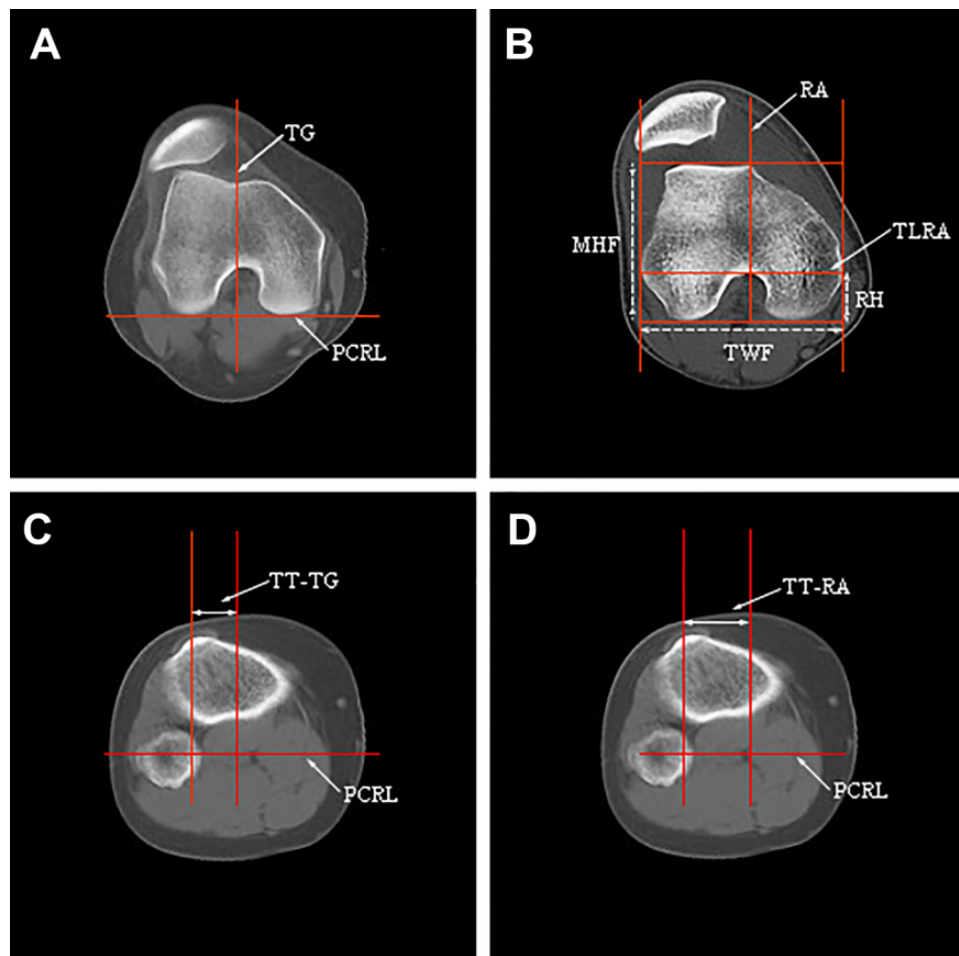


Figure 1. Method of measuring the tibial tubercle–Roman arch (TT-RA) distance and the tibial tubercle–trochlear groove (TT-TG) distance. (A) The trochlear groove is defined as a line perpendicular to the posterior condylar reference line (PCRL) and passes through the deepest portion of the trochlear groove. (B) The Roman arch is defined as a line perpendicular to the PCRL that passes through the tangent point of the Roman arch. (C and D) The distances between the 2 parallel lines (arrows) are the TT-TG distance and TT-RA distance. MHF, maximum height of the femoral condyle; RH, Roman arch height; TLRA, tangent line of Roman arch; TWF, total width of femoral condyle.

defined as the center of the tibial tubercle when the patellar tendon was completely in contact. Thus, the TT-RA distance was defined as the distance between 2 parallel lines through the bony landmark of the tibial tubercle and Roman arch that are vertical to the PCRL (Figure 1).

TT-TG Distance

The TT-TG distance was measured on CT scan according to the method described by Schoettle et al.²⁷ The bony landmark of the tibial tubercle and trochlear groove was the most anterior portion of the bony tibial tubercle and the deepest portion of the trochlear groove on the axial image. The PCRL was drawn tangent to the posterior femoral condyles at the same axial slice used to define the deepest portion of the trochlear groove. The TT-TG distance was defined as the distance between 2 parallel lines

through the bony landmark of the tibial tubercle and trochlear groove, which are perpendicular to the PCRL (Figure 1).

Trochlear Morphologic Type

The trochlea was classified according to the Dejour morphologic classification,¹³ as follows: type A, a fairly shallow trochlea with a sulcus angle greater than 145°; type B, a flat or convex trochlea; type C, a trochlea with convex lateral facet and hypoplasia medial facet; and type D, asymmetry of trochlea facets with a cliff formation.

Roman Arch Height

The Roman arch height (RH) was measured on the most proximal axial CT slice with an intact Roman arch and

TABLE 1
Comparison of Study Group and Control Group^a

Parameters	Study Group	Control Group	P Value ^b	AUC ^c
TT-RA distance, mm	23.24 ± 4.41	19.15 ± 4.24	<.001	0.757
TT-TG distance, mm	19.47 ± 4.23	15.41 ± 4.42	<.001	0.731
RH, mm	18.02 ± 1.53	17.41 ± 1.70	.045	0.602
TWF, mm	73.53 ± 5.69	77.08 ± 6.95	.003	0.317
MHF, mm	58.46 ± 3.49	59.16 ± 5.23	.400	—
TT-RA distance/RH, %	129.63 ± 25.68	110.14 ± 22.33	<.001	0.721
TT-RA distance/TWF, %	31.54 ± 5.04	24.91 ± 5.19	<.001	0.842
TT-RA distance/MHF, %	39.68 ± 6.72	32.45 ± 6.81	<.001	0.786
RH/TWF, %	24.62 ± 2.56	22.65 ± 1.88	<.001	0.721
RH/MHF, %	30.87 ± 2.47	29.47 ± 2.00	.001	0.668
TWF/MHF, %	125.78 ± 6.06	130.35 ± 4.88	<.001	0.259

^aValues are expressed as mean ± SD. Dash indicates not applicable. AUC, area under the curve; MHF, maximum height of femoral condyle; RA, Roman arch; RH, Roman arch height; TG, trochlear groove; TT, tibial tubercle; TWF, total width of femoral condyle.

^bBold figures indicate statistical significance ($P < .05$).

^cBold figures indicate that the AUC is discriminative (AUC > 0.7).

posterior femoral condyles. The perpendicular distance from the tangent point of the Roman arch to the PCRL was considered the RH (Figure 1).

Total Width of the Femoral Condyle

The total width of the femoral condyle (TWF) was measured on the proximal CT slices. Two tangent lines were drawn passing along the surface of the medial and lateral facets of the femoral condyle and perpendicular to the PCRL. The distance of these 2 lines was considered the total width of the femoral condyle (Figure 1).

Maximum Height of the Femoral Condyle

The distance from the highest point of the femoral trochlea to the PCRL measured on the CT slice was considered the maximum height of the femoral condyle (MHF)¹⁵ (Figure 1).

Statistical Analysis

All data were entered into SPSS software (Version 21.0; IBM Corp) for statistical analysis. The ratios of TT-RA distance/RH, TT-RA distance/TWF, TT-RA distance/MHF, RH/TWF, RH/MHF, and TWF/MHF were calculated to normalize data for different patient sizes. After confirming normal distribution of all parameters, we analyzed differences between the study group and control group using unpaired *t* tests. Receiver operating characteristic curve analysis was performed to evaluate the discriminatory capacity of the included parameters. For parameters with an area under the curve (AUC) greater than 0.70, the cutoff values of the parameters with sensitivity and specificity were recorded. The mean and standard deviation of the data in the control group were used to establish the pathological threshold value. The TT-TG distance and TT-RA distance were also analyzed by different Dejour classifications to evaluate the intraclass correlation coefficient (ICC)

of each parameter in different types of femoral trochlea. The ICC was calculated to assess the reliability of each parameter. Like previous authors,^{1,7,23,28} we defined an ICC greater than 0.75 as excellent agreement. A *P* value less than .05 was considered significant.

RESULTS

This study included 56 patients with a mean age of 20.5 years (range, 13-41 years) in the study group and 60 individuals with a mean age of 29.03 years (range, 14-46 years) in the control group. The sample included 15 males (27%) and 41 females (73%) in the study group and 22 males (37%) and 38 females (63%) in the control group. The mean and standard deviation for each parameter are presented in Table 1. A significant difference ($P < .001$) in TT-RA distance was found between the study group (23.24 ± 4.41 mm) and the control group (19.15 ± 4.24 mm). The TT-TG distance was 19.47 ± 4.23 mm in the study group and 15.41 ± 4.42 mm in the control group ($P < .001$). The results of our study showed a significantly wider femoral condyle and lower Roman arch in the control group than the study group ($P < .05$). Each ratio of TT-RA distance/RH, TT-RA distance/TWF, TT-RA distance/MHF, RH/TWF, RH/MHF, and TWF/MHF showed a significant difference between the study group and control group. The MHF did not show a statistical difference between the study group and control group (Table 1).

We evaluated the capacity of these parameters to predict patellar dislocation through receiver operating characteristic analysis. We defined an AUC greater than 0.7 as discriminative. Further analyses were performed when the AUC was greater than 0.7. The cutoff values of the parameters were determined to calculate the sensitivity and specificity of the value. The TT-RA distance had an AUC of 0.757. At a value greater than 23.74 mm, the TT-RA distance had 53.57% sensitivity and 88.33% specificity for predicting patellar dislocation. The TT-TG distance had an AUC of 0.731. At a value

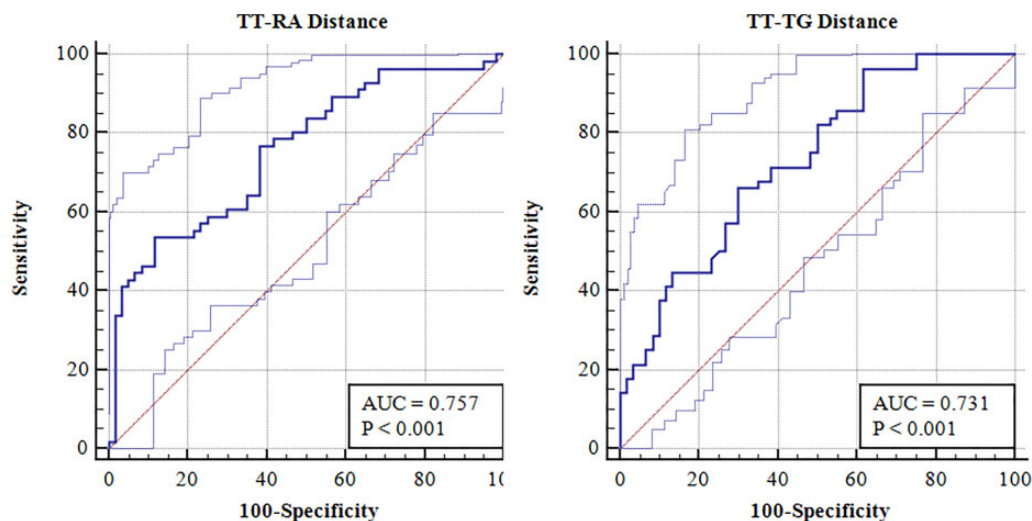


Figure 2. Receiver operating characteristic curve of tibial tubercle–Roman arch (TT-RA) distance and tibial tubercle–trochlear groove (TT-TG) distance. AUC, area under the curve.

TABLE 2
Sensitivity and Specificity of the Cutoff Values^a

	AUC	Cutoff Value	Sensitivity, %	Specificity, %
TT-RA distance	0.757	23.74 mm	53.57	88.33
TT-TG distance	0.731	17.4 mm	66.07	70.00
TT-RA distance/RH	0.721	123.96%	60.71	75.00
TT-RA distance/TWF	0.842	29.22%	80.36	83.33
TT-RA distance/MHF	0.786	34.75%	82.14	61.67
RH/TWF	0.721	24.56%	53.57	88.33

^aAUC, area under the curve; MHF, maximum height of femoral condyle; RA, Roman arch; RH, Roman arch height; TG, trochlear groove; TT, tibial tubercle; TWF, total width of femoral condyle.

greater than 17.4 mm, the TT-TG distance had 66.07% sensitivity and 70.00% specificity for predicting patellar dislocation (Figure 2). The TT-RA distance/RH had an AUC of 0.721. At a value greater than 123.96, TT-RA distance/RH had 60.71% sensitivity and 75.00% specificity for patellar dislocation. The TT-RA distance/TWF had an AUC of 0.842. At a value greater than 29.22, TT-RA distance/TWF had 80.36% sensitivity and 83.33% specificity for patellar dislocation. The TT-RA distance/MHF had an AUC of 0.786. At a value greater than 34.75, TT-RA distance/MHF had 82.14% sensitivity and 61.67% specificity. The RH/TWF had an AUC of 0.721. At a value greater than 24.56, RH/TWF had 53.57% sensitivity and 88.33% specificity. The AUCs of RH, TWF, RH/MHF, and TWF/MHF were below the threshold (0.7), so no further analysis was performed (Table 2).

Most of the patients with patellar dislocation had different degrees of trochlear dysplasia according to the Dejour classification. In the study group, 8 knees were classified as normal femoral trochlea, 20 were type A, 16 were type B, 10 were type C, and 2 were type D. In the control group, 40 knees were classified as normal femoral trochlea, 18 were type A, 1 was type B, 1 was type C, and none were type D (Table 3).

TABLE 3
Femoral Morphologic Description in Study Group and Control Group According to Dejour Classification

Dejour Classification	Study Group, n	Control Group, n
Normal	8	40
Type A	20	18
Type B	16	1
Type C	10	1
Type D	2	0

The ICC of TT-RA distance was 0.954 and the ICC of TT-TG distance was 0.848 among all the included individuals. In addition, we calculated the ICC value to analyze the reliability of TT-RA distance and TT-TG distance measurement in different Dejour classifications. We found that the ICCs of TT-RA distance measurement were excellent in any type of Dejour classification, whereas the ICCs of TT-TG distance measurements were relatively lower than the ICCs of TT-RA distance measurement. The ICC of the TT-TG distance was lower than the threshold value in type B (0.748) and type D groups (0.144). The ICC of the TT-TG distance measurement was extremely low in individuals with type D dysplasia (Table 4).

According to our data, the pathological TT-RA distance threshold was 26 mm, and 98.3% (59/60) of individuals in the control group had a value less than this. In the study group, 32.1% (18/56) of patients had a value greater than this. In the study group of patients with TT-TG distance greater than 20 mm, 64% (16/25) of patients had a value of TT-RA distance greater than 26 mm.

DISCUSSION

Our study included 56 patients and 60 healthy individuals (60 knee joints). The results of our study indicated that the

TABLE 4
Intraclass Correlation Coefficients of TT-RA Distance and TT-TG Distance in Different Dejour Classifications^a

Dejour Classification	TT-RA Distance	ICC ^b	TT-TG Distance	ICC ^b
Normal	19.74 ± 4.89	0.939	16.01 ± 5.31	0.923
Type A	21.03 ± 4.50	0.967	17.97 ± 5.02	0.854
Type B	23.19 ± 3.84	0.966	19.36 ± 4.88	0.748
Type C	22.01 ± 3.01	0.945	21.25 ± 3.51	0.784
Type D	28.48 ± 1.48	0.996	17.55 ± 2.05	0.114

^aDistances are expressed in millimeters as mean ± SD. ICC, intraclass correlation coefficient; RA, roman arch; TG, trochlear groove; TT, tibial tubercle.

^bAn ICC more than 0.75 indicated excellent agreement.

TT-RA distance in patients with patellar dislocation was significantly greater compared with included healthy individuals. TTO surgery should be considered to correct the excessive lateralization of the tibial tubercle in patients with patellar dislocation when the value of TT-RA distance is more than 26 mm. According to the distribution of TT-RA distance in the control group, the medialization of the tibial tubercle should not exceed 14 mm.

In other studies,^{3,14} excessive TT-TG distance has been regarded as a risk factor for subsequent patellar instability episodes. A TT-TG distance greater than 20 mm is the gold standard indication for TTO.^{4,12,13} However, the measurement of TT-TG distance is still controversial and has poor reproducibility in the dysplastic trochlea, especially in the flat trochlea.^{1,6,28,31} Thus, the practical value of the TT-TG distance may be limited in patients with such a condition. In our study, we analyzed the consistency of the TT-TG distance and TT-RA distance among different types of Dejour classifications, finding that the TT-RA distance had an excellent ICC in any type of Dejour classification (>0.939), whereas the ICC of the TT-TG distance measurement was relatively lower. In addition, the ICCs of the TT-TG distance measurement were extremely poor in the femoral trochlea of type B (0.748) and type D (0.114) dysplasia. The main reason for the poor reproducibility of TT-TG distance was due to the difficulty of determining the deepest point of the trochlear groove. The reason for the poor ICC value of the TT-TG distance measurement specifically in type D trochlea could be a result of small sample size (only 2 individuals). The relatively lower ICC value for the TT-TG distance measurement was similar to the findings of previous studies.^{6,8,23,29} However, the ICC for the TT-TG distance measurement was extremely high (>0.98) in other studies that did not analyze the parameter of trochlea dysplasia.^{7,16,19} We think that in cases of high-grade dysplastic trochlea, a high ICC value for TT-TG distance is extremely difficult to achieve. Our results showed that TT-RA distance may be more appropriate to identify the relative position of the tibial tubercle in patients with trochlear dysplasia because of its extremely high ICC value.

Our data suggest that TT-RA distance and TT-TG distance had good diagnostic values for patellar dislocation

with an AUC greater than 0.7. In addition, we found that the ratios of TT-RA distance/TWF (AUC, 0.842) and TT-RA distance/MHF (AUC, 0.786) had stronger capacities to predict patellar dislocation compared with TT-TG distance alone. Instead of using TT-TG distance alone, some investigators have attempted to combine TT-TG in a ratio with additional parameters, such as patellar or trochlear width, to predict patellar dislocation.^{7,9,17,18,20} These studies showed that the ratio of TT-TG distance to a specific parameter of the knee joint had a stronger ability to predict patellar dislocation than TT-TG distance alone. Therefore, when the TWF, MHF, and RH were analyzed in the proximal CT slice, the results showed that the ratios of TT-RA distance/TWF and TT-RA distance/MHF had a stronger capacity to predict patellar dislocation than the TT-RA distance alone. Given the availability of existing studies on the ratio of TT-TG distance, the ratio of TT-TG distance to some anatomic parameters can have a more effective value to predict patellar dislocation. Therefore, we did not analyze any ratio of TT-TG distance in this study.

Based on the findings of our study, the TT-RA distance is a more reliable parameter for identifying the relative position of the tibial tubercle in patients with patellar dislocation and expands the measurements used to predict the occurrence of patellar dislocation. The parameters of TT-RA distance, TT-RA distance/TWF, and TT-RA distance/MHF had high sensitivity and specificity in the diagnosis of patellar dislocation. Our data suggest that due to its high ICC and AUC, the measurement of TT-RA distance is superior to the measurement of TT-TG distance alone in evaluating tibial tubercle displacement in patients with trochlear dysplasia.

The strength of our study included the recruitment of healthy volunteers and the randomized fashion of measurements. Several studies have established new parameters to predict patellar dislocation but included patients with anterior cruciate ligament tear or without patellofemoral pain as the control group, which may introduce potential bias.^{18,23,24} In addition, the measurements in our study were performed simultaneously by a radiologist and an orthopaedic surgeon using standard protocols to increase the reliability of the results. Moreover, our study provided evidence and recommendations for the diagnosis and surgical treatment of patellar dislocation. According to our statistical analysis of healthy individuals, the physiological range of TT-RA distance was 12 to 26 mm. In patients with TT-RA distance greater than 26 mm, TTO should be considered to correct the excessive lateralization of the tibial tubercle, and the medialization of the tibial tubercle should not exceed 14 mm or fall out of this physiological range (12-26 mm). Excessive medialization of the tibial tubercle in patients with patellar dislocation may result in iatrogenic medial patellar dislocation.

Most prior studies offering alternative parameters to assess anatomic differences in tibial tubercle offset between controls and patients with patellar dislocation do not offer any recommendations for the treatment of patellar dislocation.^{23,28} Seitlinger et al²⁸ introduced a novel tibial tubercle–posterior cruciate ligament (TT-PCL) distance to define the position of the tibial tubercle in patients with patellar dislocation. Those authors considered a TT-PCL

distance of less than 24 mm as normal but failed to provide the cutoff value at which surgical intervention was needed. They reported that the correlation between TT-PCL distance and TT-TG distance was low ($R^2 = 0.34$).²⁸ Mistovich et al²³ established a novel patellar tendon–lateral trochlear ridge (PT-LTR) distance to assess how well the trochlea contained the extensor mechanism; the investigators concluded that this parameter was reliable, predictable, and discriminative for patellofemoral dislocations. However, the measurement of PT-LTR distance could not provide any insight regarding treatment, thus limiting its practical value. Contrary to these studies, in the current study, the high reproducibility and obvious surgical cutoff value rendered the measurement of TT-RA distance superior to TT-PCL and TT-LTR distance.

Our study had some limitations. First, we analyzed the parameters in 116 patients, whereas the normal values of TT-RA distance and other parameters were calculated on 60 knee joints in healthy individuals. The threshold of TT-RA distance may change in a relatively larger population. Second, we evaluated the ratio of TT-RA distance and other parameters for only the femoral condyle, but tibial anatomic parameters may also influence the diagnosis or treatment plan formulated in patients with patellar dislocation. Third, the number of patients with type C and type D trochlear dysplasia according to the Dejour classification was low. This is a possible reason for extremely low ICC value in patients with type D trochlear dysplasia.

CONCLUSION

Our study showed that the TT-RA distance is a reliable parameter for identifying the relative position of the tibial tubercle in patients with patellar dislocation. Compared with TT-TG distance, TT-RA distance provides a more clinically reliable measurement for individuals with trochlear dysplasia. For patients with TT-RA distance greater than 26 mm, TTO should be considered to correct the malposition of the tibial tubercle.

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