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Novel techniques

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

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ABSTRACT

Background: To determine whether 3D-CT imaging technique is valid and reproducible compared to conventional CT measurement technique (CCT) for the detection of a femoropatellar instability.
Methods: Patients who had undergone surgery for femoropatellar instability (patellar instability group) between 2010 and 2016 (n = 37 knees of 35 patients) were retrospectively enrolled. For the matched control group, patients who had acute anterior cruciate ligament injury (<4 weeks previously; n = 30) were recruited. Preoperative CT data had been obtained in all patients. Inter-rater reliability was calculated for both measurement protocols, and inter-method reliability was calculated between the two imaging modalities. The results are reported using intraclass correlation coefficients (ICCs) and Bland–Altman 95% limits of agreement.
Results: All patients in the patellar instability group had femoral trochlear dysplasia (Dejour types A: four, B: 19, C: seven, and D: six), but no dysplasia was noted in the control group. In the patellar instability group, the CCT technique showed a poor inter-rater agreement (ICC = 0.74), and the 3D-CT technique still showed excellent inter-rater agreement (ICCs = 0.91). In the sub-analysis of the patellar instability group according to the trochlear dysplasia grade, ICCs were markedly decreased with severe trochlear dysplasia when using CCT technique; however, the 3D-CT technique could provide excellent reliability even with severe trochlear dysplasia.
Conclusion: The 3D-CT imaging technique for the measurement of the TT–TG distance can be suggested as a better measurement technique for patellar instability patients with bone abnormality.

1. Introduction

The distance between the tibial tuberosity and the trochlear groove (TT–TG) is a widely used parameter for femoropatellar instability [1]. TT–TG is an index representing tibial tuberosity position relative to the trochlear groove. Precise TT–TG measurement

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is integral to judging the operative indication of tibial tuberosity medialization. TT–TG of >15 mm is considered a risk factor for femoropatellar instability [2]. For patients with increased TT–TG of >20 mm, distal realignment procedures, such as Fulkerson's operation, are suggested [3,4]. Meanwhile, over-medialization of the tibial tuberosity during operation could increase the patellofemoral (PF) pressure [5–7]. Therefore, accurate assessment of the TT–TG distance is important during the surgical planning and success of tuberosity medialization.

TT–TG has been assessed on the axial Computed Tomography scans as described by Goutallier et al. [8]. References used are the deepest point of the trochlear groove and the most cephalad point of the tibial tubercle [9,10]. However, the trochlear groove is a three dimensional (3D) arc, which has a rotational component and coronal orientation [11,12]. Reference points including posterior condylar line, the deepest point of the trochlear groove, and tibial tubercle are not on the same axial plane. They can lead to a low intra- and inter-observer reliability to measure the distance. In particular, the measurement accuracy is confronted by a difficulty in identifying the deepest point in the trochlear groove with trochlear dysplasia. A previous study has reported inter-observer agreement of TT–TG measurement (<60%) in patients with trochlear dysplasia [13].

To decrease the measurement errors by the previous protocol for the double-image technique, Koëter et al. [14] suggested a new single-image technique of the CT measurement (they described that identification of the anatomical structures on the superimposed maximum intensity projection can be difficult). Julliard [15] suggested another technique to determine TT–TG distance: estimation of the cranial trochlear groove point by the overlying images of the trochlea using the center of the patellar tendon insertion.

However, determining the deepest point within the trochlear groove in severe trochlear dysplasia remains difficult. This study was conducted under the hypothesis that a better identification of trochlear groove geometry from the whole 3D images would allow accurate and reproducible TT–TG assessment, even with variations types of trochlear dysplasia [16].

The aims of this study were to introduce our TT–TG measurement method using a 3D-CT image model, and also to compare the reliability of a new method based on 3D-CT to the previously described CT-based method to determine the TT–TG distance. For each method, the results measured by two observers were reported using intraclass correlation coefficients (ICCs) and Bland–Altman analysis. Specifically, we sought to determine whether the 3D-CT imaging technique, introduced in this study, provides more accurate and reliable measurement of TT–TG distance in patients with patellar instability compared with the conventional CT-based technique. It was hypothesized that a newly suggested 3D-CT-based method for TT–TG measurement would promote lower measurement bias and improve the reliability and reproducibility in patients with femoropatellar instability.

2. Material and methods

2.1. Patients

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The current study obtained Institutional Review Board approval (Number: 2016-09-007) from our institution before study onset, and our protocol was also approved. Informed consent was obtained from all participants.

From March 2010 to June 2016, all patients with femoropatellar instability (defined as more than two episodes of dislocation or one episode of dislocation plus multiple episodes of instability (lateral excursion of the patella without dislocation)) were eligible to participate in the study. In total, 37 knees in 35 patients (mean and standard deviation age, 18.5 ± 6.2 years; 18 men and 17 women) were included. They underwent two types of operation: (1) medial patellofemoral ligament reconstruction with arthroscopic lateral release (n = 31); and (2) distal re-alignment procedure, such as Fulkerson's operation [3], with arthroscopic lateral release and medial patellofemoral ligament reconstruction or medial reefing (n = 6). Trochlear dysplasia was categorized based on the Dejour classification scale [17–19]. All patients in the patellar instability group showed evidences of trochlear dysplasia, with Dejour type B as the most common (type A, six knees; type B, 19 knees; type C, six knees; type D, six knees).

For the matched control group based on age and sex, patients without patellar instability symptoms or femoral trochlear dysplasia, who had undergone anterior cruciate ligament reconstruction, were recruited. A total of 30 knees in 30 patients (mean age, 20.8 ± 4.1 years; 16 men 14 women) were enrolled with CT images revealing normal femoral condylar morphology. The difference in age, sex distribution, and body mass index (BMI) between the two groups was not significant.

2.2. Imaging protocols

2.2.1. TT–TG on conventional CT measurement

All images and examinations were respectively acquired and performed using the same CT scanner (Somatom Plus 4, Siemens Medical Solutions, Erlangen, Germany). The CT scans were performed first on a single-detector CT system using a bone algorithm (section thickness of three millimeters, 120 kV, and 146 mA). In all cases, patients were placed in a supine position with 30° of flexion and neutral rotation of the knee joint in the CT scanner.

The images were measured using picture archiving and communication system (PACS) View software. The TT–TG distance on the conventional CT (CCT) images was measured as suggested by S. Koëter et al. [14]. Between the most cephalad point of the tibial tubercle and the deepest point of the trochlear groove [9,10], the trochlear line was drawn perpendicular to the posterior condylar line and passing through the deepest point of the trochlear groove. Trochlear groove location was specified as the deepest point of the trochlear groove at the level on which the posterior cortices of the femoral condyles were well defined

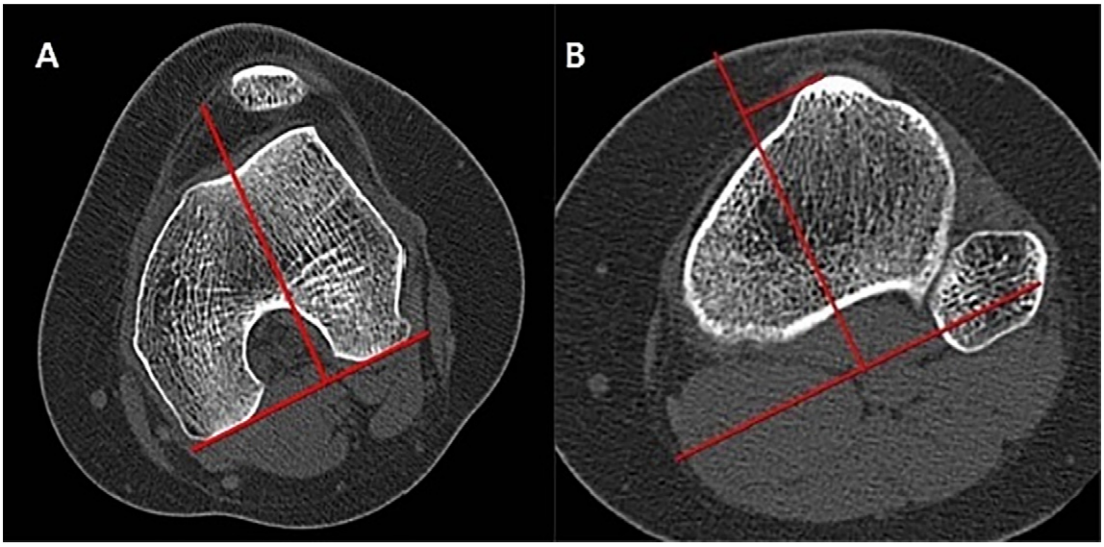

Figure 1. Tibial tubercle–trochlear groove (TT–TG) distance on conventional computed tomography (CCT) measurement. (a) First the trochlear line was drawn perpendicular to the posterior condylar line and passing through the deepest point of the trochlear groove. (b) These lines were copied to the images depicting the tibial tuberosity. The distance between the trochlear line and middle of the tibial tuberosity was measured in millimeters.

[14]. The lines first drawn on the axial section tangential to the posterior femoral condyles and a perpendicular line through the deepest point of the trochlea (Figure 1(a)) were transferred to the axial section with the most anterior point of the tibial tuberosity, and a perpendicular line to the baseline through the most anterior point of the tibial tuberosity was drawn. Then, the distance between the two perpendicular lines was measured in millimeters (Figure 1(b)).

2.2.2. TT–TG distance on 3D-CT measurement

In all patients, CT images taken prior to the operation were converted to 3D-CT reconstruction images.

Three dimensional surface-rendering reconstructions (Advantages Windows, General Electric, Erlangen, Germany) were performed for each case. A threshold was set at 160 HU in shaded-surface display. The distal femur and proximal tibia were extracted from the patella. A 3D surface rendering was then performed. An imaginary horizontal line was drawn through the center of the patella. In order to evaluate the trochlear line, the scan was oriented after the best fit to concentrate on the vertical section of the line. Then, the tuberosity line connecting two most cephalad points of the tibial tubercle could also be made onto the tibial tuberosity of 3D-CT model easily. TT–TG distance was measured along the first imaginary horizontal line drawn through the center of the patella (Figure 2).

2.3. Statistical analysis

Patient and radiographic alignment data are expressed as mean and standard deviation [20]. The Wilcoxon signed-rank test was used to determine the difference between measurements using CCT technique and 3D-CT technique. Mann–Whitney *U*-test was used to determine the differences in measurements between patellar instability group and matched control group. For each knee, two independent observers (fellowship of sports medicine) conducted the measurements. However, they were blinded to each other's measurements and their prior measurements. Each observer performed each measurement technique on each knee scan. There was a minimum interval of two weeks between the duplicate measurements per technique and a two-week interval between the two techniques. Neither of the observers was involved in the treatment of the patients or had any knowledge of their clinical data. Inter-rater reliability of two imaging methods (CCT and 3D-CT) and agreement between the two methods were evaluated. This was accomplished by calculating two separate measures of agreement: the ICC [21] and Bland–Altman 95% limits of agreement (LOA) [22]. Both of these measures were reported with their corresponding 95% confidence intervals (CIs). The ICC values were interpreted as follows: ICC of <0.40: poor agreement; ICCs of 0.40–0.75: fair-to-good agreement; and ICC of >0.75: excellent agreement [23]. Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) ver. 12.0 (SPSS Inc., Chicago, IL, USA). A priori power analysis was performed to determine the sample size using the two-sided hypothesis test at a level of 0.05 and a power of 0.8. The calculations based on the sample size of 40 patients in each group indicated adequate power (0.93–0.99) to detect a significant difference in measurement outcomes in the present study.

3. Results

As previously mentioned, 35 patients in the patellar instability group and 30 in the matched control group were included in this retrospective study. No differences in preoperative demographic data were observed between the two groups (Table 1).

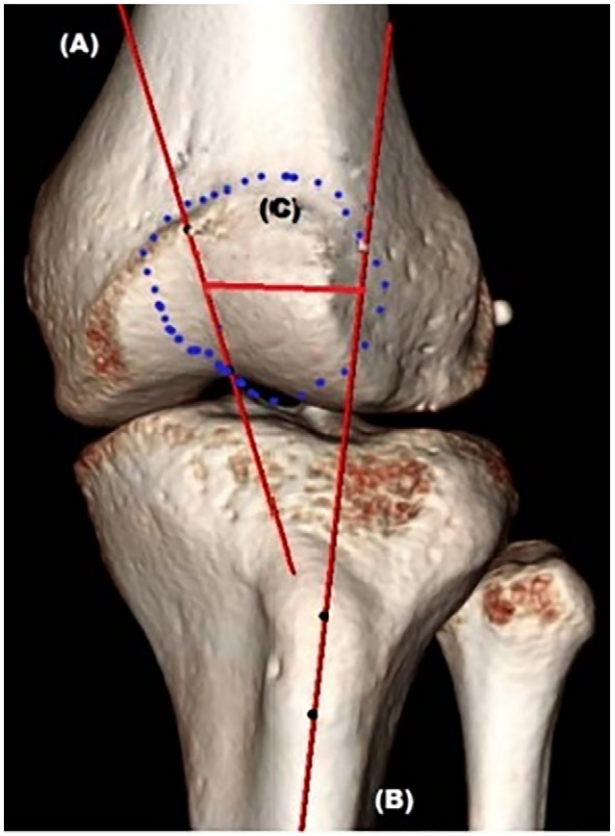

Figure 2. Tibial tubercle–trochlear groove (TT–TG) on three-dimensional computed tomography measurement. (A) The trochlear line connecting the two deepest points of trochlear groove and (B) the tuberosity line connecting two most cephalad points of the tibial tubercle. (C) TT–TG line at the horizontal midpoint of the patella.

TT–TG was significantly longer in patients with patellar instability than in patients in the matched control group (14.9 ± 3.8 mm, 7.7 ± 2.0 mm measured by CCT technique, $P < 0.001$).

3.1. Interclass correlations

Details of inter-rater agreement measures, including observed bias, lower and upper bounds of 95% CIs, and lower and upper 95% LOA, are presented in Tables 2 and 3.

In the patellar instability group, the mean TT–TG as measured by raters 1 and 2 was 14.9 ± 3.8 mm and 14.4 ± 3.7 mm on CCT technique, respectively; on 3D-CT, the corresponding values were 14.8 ± 4.4 mm and 14.7 ± 4.0 mm, respectively. There was no significant difference in the mean value of TT–TG between two measurement techniques, while two techniques showed different measurement reliability and variability between the raters. CCT technique showed fair-to-good inter-rater ICCs (0.736; 95% CI, 0.526–0.874). The 3D-CT technique still showed excellent inter-rater ICCs (0.911; 95% CI, 0.864–0.990) (Table 2). The evaluation between raters using Bland–Altman analysis revealed increased variability, observed bias/mean TT–TG difference between raters 1

Table 1
Comparison of patients' demographics and tibial tuberosity–trochlear groove (TT–TG) distances between the two groups.

	Patellar instability group (n = 37)	Matched control group (n = 30)	P[b]
Age (years)[a]	18.5 ± 6.2	20.8 ± 4.1	0.080
Sex (M/F)	17:20	16:14	0.627
BMI (kg/m^2)[a]	26.5 ± 4.4	24.8 ± 3.8	0.136
TT–TG distance (mm)[a]			
Using CCT technique	14.9 ± 3.8	7.7 ± 2.0	<0.001
Using 3D-CT technique	14.8 ± 4.4	8.0 ± 1.8	<0.001

CCT, conventional computed tomography; 3D-CT, three-dimensional computed tomography.
[a] Values are expressed as mean ± standard deviation.
[b] The independent *t*-test was used to compare the two groups in terms of demographic data (age and body mass index). The Fisher exact test was used for comparing the sex distribution between the groups.

Table 2
Inter-rater agreement of tibial tuberosity–trochlear groove distance measurement for the matched control group.

Inter-rater reliability		ICCs (95% CI)		*P*
Matched control group	Conventional	0.903	(0.797–0.954)	<0.001
	3D-CT	0.905	(0.800–0.955)	<0.001
Patellar instability group	Conventional	0.736	(0.526–0.874)	<0.001
	3D-CT	0.911	(0.864–0.990)	<0.001

CI, confidence interval; ICC, intra-class correlation coefficient; 3D-CT, 3-dimensional computed tomography.

and 2 of 0.5 mm (95% LOA, −5.6 to 6.6) on the CCT technique and 0.1 mm (95% LOA, −1.7 to 1.4) on the 3D-CT technique (Figure 3(c), (d)).

However, for the matched control group, both measurement techniques showed an excellent reliability for TT–TG distance measurement (inter-rater ICCs; 0.903 on CCT and 0.905 on 3D-CT technique) (Table 2). Neither CCT nor 3D-CT showed significant bias or variability between the raters. The evaluation between raters using Bland–Altman analysis demonstrated an observed bias/mean TT–TG difference between raters 1 and 2 of 0.2 mm (95% LOA, −2.2 to 2.6) on the CCT technique and −0.2 mm (95% LOA, −2.3 to 2.0) on the 3D-CT technique (Figure 3(a), (b)).

In the sub-analysis of the patellar instability group based on trochlear dysplasia grade, ICCs were markedly decreased with severe trochlear dysplasia when using the CCT technique; however, 3D-CT technique could provide excellent reliability even with severe grade (Figure 4). (Further details are available in a Supplementary Table S1.)

4. Discussion

This study demonstrated a new method based on a 3D-CT image modeling and showed lower measurement bias and improved the reliability for the measurement of TT–TG distance with severe femoral hypoplasia. For the patellar instability group, conventional CT measurement showed fair-to-good inter-rater ICCs of 0.74, while 3D-CT technique showed excellent inter-rater ICCs of 0.91, also smaller inter-rater variability of TT–TG difference was observed using 3D-CT technique in Bland–Altman analysis.

TT–TG measurement with high reliability using a 3D-CT model can be explained under the theoretical basis of the sulcus line applicable as rotational alignment of the distal femur during the total knee arthroplasty [24]. The sulcus line is a curve derived from joining multiple points along the depth of the trochlear groove. The sulcus line has been more accurate than Whiteside's line, and is defined as the axis taken from the two points: the deepest part of the patella groove anterior to the center of the intercondylar notch posteriorly [11,12]. A trochlear line on the 3D-CT surface model might not correspond exactly with the sulcus line because it was assessed at 90° of the knee flexion angle. However, both the trochlear and sulcus lines are established by instinctively identifying the trochlear groove geometry with relative ease. This vertical section is not affected by the trochlear dysplasia and patellofemoral osteoarthritis that can obliterate the proximal section of the groove.

In the conventional CT technique, TT–TG was measured only by one deepest point of the trochlear groove [9,10]. However, identifying a precise, deepest point of the trochlear groove and reliable posterior condylar line in the trochlear dysplasia is difficult. Meanwhile, a 'trochlear line' connecting the deepest points of trochlear groove can be established easily, with the identification of trochlear groove geometry on a 3D-CT surface model.

Another strength of the present study is that TT–TG was measured based on the CT images acquired with 30° of flexion and neutral rotation of the knee joint. The position of the tibial tubercle relative to the femoral epicondyles varies with the flexion angle [25]. Knee flexion decreases external tibial rotation, medializing the tibial tuberosity and decreasing TT–TG distance. However, patellar lateral displacement is maximum at 30° knee flexion with the lowest restraining force [25,26]. Therefore, TT–TG was measured and compared on the CT scan taken at 30° knee flexion in the present study, which would be more representative in deciding the position of the patella relative to the femoral condyles despite the various positions of the tibial tubercle with flexion angle.

In patients with abnormal trochlear anatomy, the definition of reference points might be more difficult. For example, although Dornacher et al. reported good intra- and inter-rater agreements in cases of Dejour types A and B trochlear dysplasia, the results deteriorated in cases of patients with high-grade trochlear dysplasia. They concluded that the deepest point in the trochlear groove was not reproducibly defined [27]. Similarly, the current study reinforced their results that the inter-rater reliability of TT–TG measurement in patients with Dejour types C (fair) and D (poor) was markedly declined. However, the results improved

Table 3
Results of the Bland–Altman analysis.

Bland–Altman analysis		Difference (mean, mm)	95% LOA (mm)
Control group	Conventional	0.2	−2.2 to 2.6
	3D-CT	−0.2	−2.3 to 2.0
Patellar instability group	Conventional	0.5	−5.6 to 6.6
	3D-CT	0.1	−1.7 to 1.4

LOA, limits of agreement; 3D-CT, three-dimensional computed tomography.

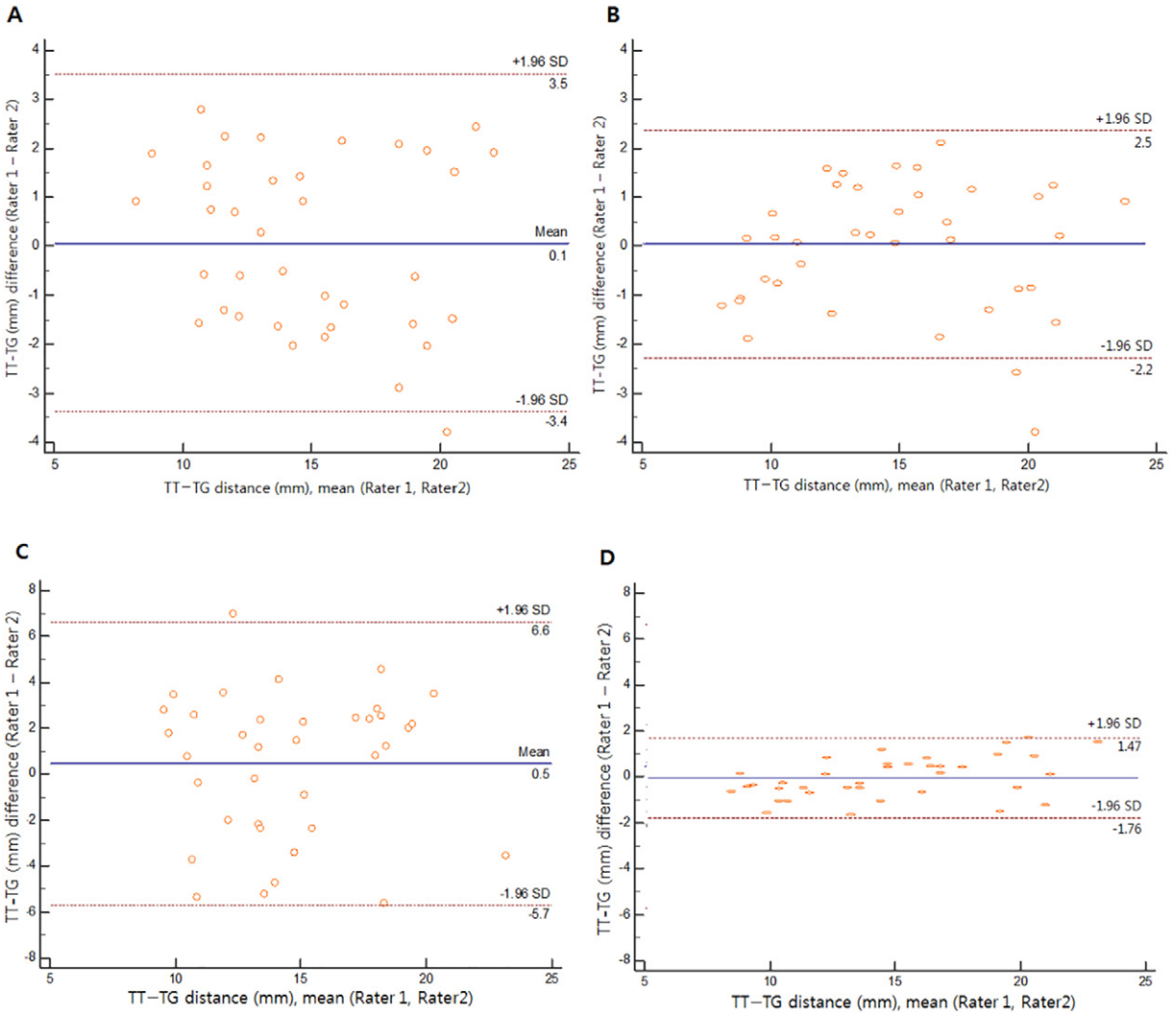

Figure 3. Bland–Altman plots of differences between two raters on (a) conventional computed tomography (CCT) and (b) three-dimensional computed tomography (3D-CT) for the matched control group, as well as (c) CCT and (d) 3D-CT for the patellar instability group. Bland–Altman plots of inter-rater differences on (a) CCT and (b) 3D-CT reveal little bias or variability in the patellar instability group.

for 3D-CT. Moreover, the inter-rater correlations had excellent reliability in patients with Dejour types C (ICCs = 0.96) and D (ICCs = 0.82). The suggested 3D-CT technique demonstrated accurate TT–TG calculation, and the same was true for the conventional CT-based method in the control group with normal geometry. However, in light of the lower ICCs and higher discrepancy on Bland–Altman analysis for intermethod reliability using the conventional CT-based method in the patellar instability group, this study suggests that the 3D-CT technique has lower variability and inter-rater difference.

Our measurement technique using a 3D-CT surface model showed that it can also be used as an alternative diagnostic tool in patients with normal femoral trochlear morphology through the assessment of the matched control group (patients who had acute anterior cruciate ligament injury with no femoral trochlear dysplasia). There was an excellent reliability at the similar level of intra- and inter-rater agreement and little bias. The 3D-CT technique did not require the extra-radiation exposure and cost as compared to the conventional CT measurement method. Further 3D-CT reconstruction images were processed with additional 3D software in order to provide better anatomical images for the measurement after CT images were obtained.

Nevertheless, the present study has several limitations. First, the possibility of measurement error due to patient positioning inconsistency was not eliminated by the new technique using 3D-CT reconstruction images [28]. However, we made every effort to standardize the patient's position to supine, and the leg placed in neutral rotation with 30° flexed knee joints. Third, the matched control group comprised of anterior cruciate ligament injury patients, and might not adequately represent the normal femoral condylar anatomy of the normal patients. Further prospective studies with more homogeneous cohorts will be required to establish the normal range of measured TT–TG distance and its reproducibility between the conventional CT-based method and the 3D-CT technique.

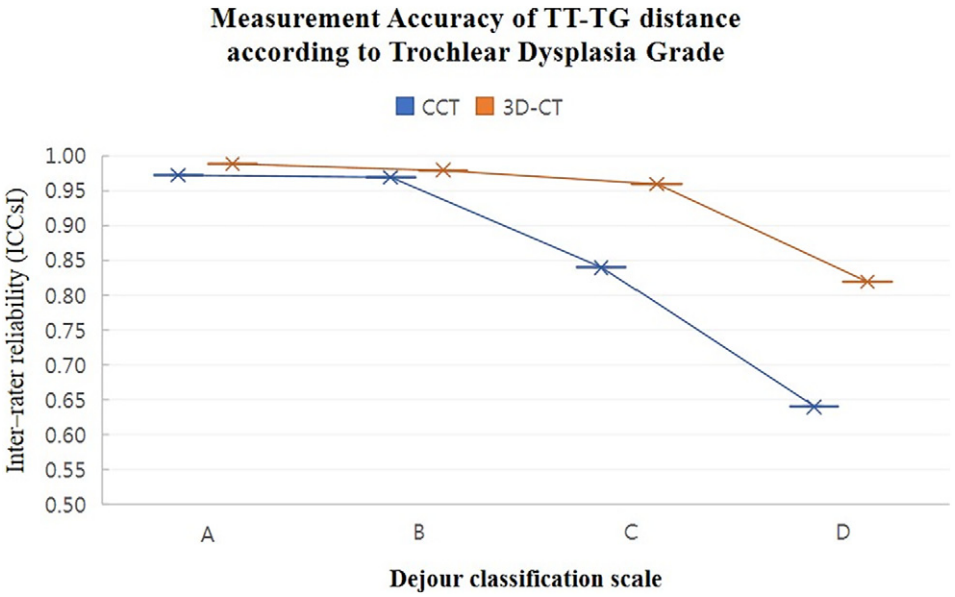

Figure 4. Inter-rater agreement of the tibial tuberosity–trochlear groove (TT–TG) measurement in the patellar instability group according to trochlear dysplasia grade. CCT, conventional computed tomography; 3D-CT, three-dimensional computed tomography.

5. Conclusion

The 3D-CT imaging technique for the measurement of the TT–TG distance can be suggested as a better measurement technique for patellar instability patients with bone abnormality.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.knee.2019.05.001.

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