Analyzing Alignment Error in Tibial Tuberosity–Trochlear Groove Distance in Clinical Scans Using 2D and 3D Methods

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Background: Tibial tuberosity–trochlear groove distance (TT-TG) is often used as a primary metric for surgical decision-making in the treatment of patellofemoral instability (PFI), particularly when considering tibial tubercle transfer. Although TT-TG has high interrater reliability, it is prone to measurement differences caused by the alignment of the patient's leg in a scanner gantry, potentially influencing surgical decision-making. Quantification of this error within the clinical literature remains limited.

Purpose: To quantify and specify the error in TT-TG caused by leg-scanner alignment by using detailed topographical landmarks and 3-dimensional (3D) analysis of computed tomography scans of patients with PFI.

Study Design: Controlled laboratory study.

Methods: Three-dimensional models of knees with PFI were created from computed tomography scans and used to identify TT-TG landmarks. TT-TG was measured using the established 2-dimensional (2D) and 3D methods. A model to estimate the differences between these 2 methods was created, and the orientation of the patients' legs in relation to scanner longitudinal axis was measured to validate this model via linear regression. Interrater reliability was calculated via intraclass correlation coefficients (ICC).

Results: A total of 44 knees of patients with PFI were analyzed. Differences between the 2D and 3D methods ranged from -4.0 to 14.7 mm (mean ± SD, 2.7 ± 4.1 mm) with a root mean square difference of 4.8 mm. The TT-TG distance of the 2D method (19.8 ± 7.2 mm) was significantly (P = .045) longer than that of the 3D method (17.1 ± 4.9 mm). The variance of the 2D method was significantly larger than that of the 3D method. In total, 13 (29.5%) of the knees had a difference of >5 mm between 2D and 3D TT-TG. The estimation model had an adjusted r^2 value of 1.00 and a resulting root mean square difference of 0.21 mm. 3D TT-TGs interrater reliability was good to excellent (ICC, 0.94 [95 CI%, 0.81-0.98]).

Conclusion: 3D TT-TG can be used to correct scanner-leg alignment errors, some of which are substantial when using only 2D TT-TG measurements.

Clinical Relevance: The findings in this study suggest a need for caution and awareness of the potential effects of differences in alignment of the axes of the leg and scanner when using purely 2D TT-TG as a basis for surgical planning.

Keywords: patellofemoral instability; tibial tuberosity to trochlear groove distance (TT-TG); alignment error; three-dimensional (3D) analysis

Patellofemoral instability (PFI) is a common condition among pediatric and adolescent athletes[13] with a prevalence of patellar dislocation as high as 43 per 100,000 in pediatric patients.[15] Understanding patellar instability is important in improving quality of life, minimizing risk of early onset osteoarthritis and understanding patellofemoral pain.[19] In 1994, Henri Dejour and colleagues[7] established that the cause of patellar instability is multifactorial and formulated 4 primary risk factors, still broadly applied in clinical decision-making today. They focused on (1) trochlear dysplasia, (2) quadriceps dysplasia, (3) patella alta (ie, Caton-Deschamps index of ≥1.2), and (4) a tibial tuberosity–trochlear groove (TT-TG) distance of ≥20 mm. TT-TG distance plays a pivotal role in decisions about when to move a tibial tubercle, as a large TT-TG distance signifies an increased lateralizing tracking force on the patella.[5,12,14]

Measurements of TT-TG taken from magnetic resonance imaging (MRI) or computed tomography (CT) scans of extended knees are widely considered one of the most important metrics in surgical planning for patients with patellar instability.[1,6] TT-TG has been found to have high interrater reliability,[22] but concerns have been raised that alignment of a patient's leg within the scanner might reasonably alter the measurement.[8,23] The potential for such error warrants concern because the threshold of 20

The American Journal of Sports Medicine
2024;52(12):2996–3003
DOI: 10.1177/03635465241279852

mm established by Dejour et al[7] plays a critical role in surgical decision-making regarding tibial tubercle osteotomy and transfer. Considering that many patients can experience relief from patellar instability with a medial soft tissue reconstruction alone, deciding which patients benefit most from the additional morbidity of a tibial tubercle osteotomy deserves the utmost precision.[7,14]

Two-dimensional (2D) TT-TG measurement is inherently prone to errors because it seeks to simplify a very complex 3-dimensional (3D) structure using a 2D measurement. The purpose of this study was to quantify and specify the error in TT-TG caused by leg-scanner alignment by using detailed topographical landmarks and 3D analysis of CT scans of patients with PFI. It was hypothesized that a linear regression model could be used to estimate the difference caused by alignment between the 2D and 3D methods almost perfectly.

METHODS

2D and 3D TT-TG

The traditional TT-TG measurement method (2D TT-TG) relies on a knee being aligned with the scanner's longitudinal axis (SLA). Alterations of a TT-TG measurement will increase the more the knee's axial orientation deviates from the SLA. Three orientations relative to the SLA are relevant: coronal, sagittal, and axial (ie, the orientation of the posterior condylar line (Figure 1). Coronal rotation of the whole knee or leg moves the TT mediolaterally relative to the TG. Sagittal rotation of the whole knee or leg moves the TT anteroposteriorly relative to the TG. Depending on the posterior condlye line angle, those 2 rotations will have different effects on the measured TT-TG (Figure 2). How much the TT moves on the axial plane due to sagittal and coronal rotation is proportional to the vertical distance between the TT and the TG. These considerations lead to equation 1:

$$\begin{gathered} \textit{Difference due to alignment} \approx d * (\sin(\alpha) * \cos(\gamma) \\ + \sin(\beta) * \sin(\gamma)) \\ d \ldots \textit{Vertical distance TT to TG} \\ \alpha, \beta, \gamma \ldots \textit{Coronal, sagittal, and PCL Rotation} \\ \text{(see Figure 1)} \end{gathered} \tag{1}$$

A more sophisticated technique to measure TT-TG to overcome these issues is needed. Contrary to the 2D method, the 3D method introduced in this article is used to calculate TT-TG independent of patient orientation in the scanner, and the coordinate system is defined by the scanner by utilizing the tibial longitudinal axis (TLA) as reference. As a result, this method removes the described scanner alignment error and makes TT-TG only dependent on the conditions within the knee and how raters place the landmarks. The alignment of the TLA in relation to the SLA and its effect on TT-TG can be described by the same sagittal, coronal, and posterior condlye line rotation and vertical distance between TT and TG as highlighted before.

To test the hypothesis that 2D TT-TG is prone to scanner-leg alignment errors, CT scans (see patient selection subsection) were selected and segmented. 3D landmarks were placed, and their coordinates were inputted into algorithms outputting both 2D and 3D forms of TT-TG and the angular alignments of the TLA to the SLA. The results were input into a difference estimation model built on the given equation 1, and corresponding statistical metrics were recorded. Each step is described in more detail below.

Institution and Study Design

This study was conducted within a major university orthopaedic department within a patellofemoral research program focused on the treatment of patellar instability in collaboration with the university's school of engineering. The study is based on retrospective imaging studies acquired within the standard of care within this system. This study was deemed exempt by the institution's institutional review board.

Patient Selection

Patients with PFI from our institution's medical record database primarily treated by the senior author (J.P.F.) between January 2020 and December 2023 with ≥2 patellar dislocation events were selected and included if high-resolution CT scans were available. Included patient scans were used for the evaluation of patellar instability in clinical practice. An initial cohort of 40 knees was selected for 2D and 3D TT measurement, and the results were used to calculate adequate sample size with a power calculation. Afterward, the cohort size was extended to reach the intended power level. Patient knees crossing over the other leg, in a flexion angle of >30°, or with previous surgeries affecting TT-TG (eg, TT osteotomy) were excluded.

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Submitted February 14, 2024; accepted August 6, 2024.

Presented as a poster at the AOSSM annual meeting, Denver, Colorado, July 2024.

One or more of the authors has declared the following potential conflict of interest or source of funding: D.H.W. has received support for education from Zimmer Biomet, Smith & Nephew, Intellijoint Surgical, and Stryker and consulting fees from Globus Medical. J.P.F. has received consulting fees from Linvatec Corp and a grant from Encore Medical. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

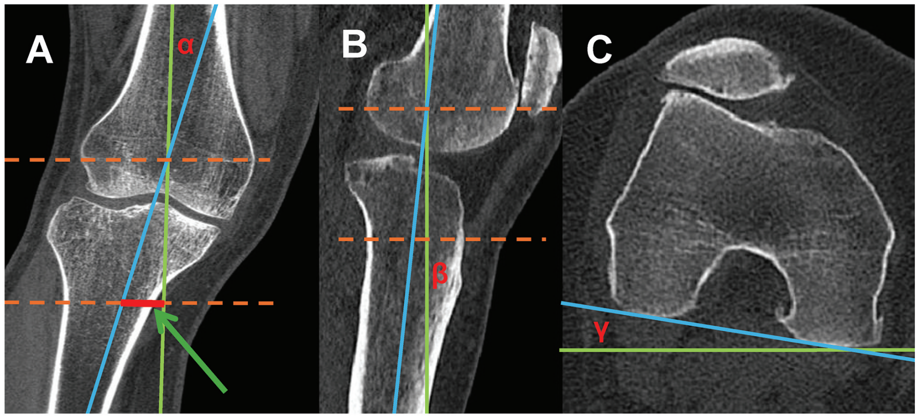

Figure 1. The base assumption for traditional 2-dimensional (2D) tibial tuberosity–trochlear groove (TT-TG) distance is that the knee axis is aligned with the scanner coordinate system,[22] which is not necessarily the case. (A) The tibial longitudinal axis (TLA) (blue line) deviates from the scanner's longitudinal axis (SLA) (green line) in the coronal plane by the angle (α). In the case the posterior condylar line is horizontal ($\gamma = 0°$), the length of the red line (green arrow) is the difference between 2D and 3-dimensional TT-TG (see equation 1 with $\cos(\gamma) = 1$ and $\sin(\gamma) = 0$). The dashed lines (orange) indicate where the axial slices for the TT-TG measurement would be, and the distance between the 2 slices is the vertical distance between the TT and TG. (B) The sagittal rotation angle (β) describes the alignment between the TLA and the SLA on the sagittal plane. (C) The posterior condylar line rotation angle (γ) describes the alignment of the posterior condylar line and the horizontal scanner axis on the axial slice.

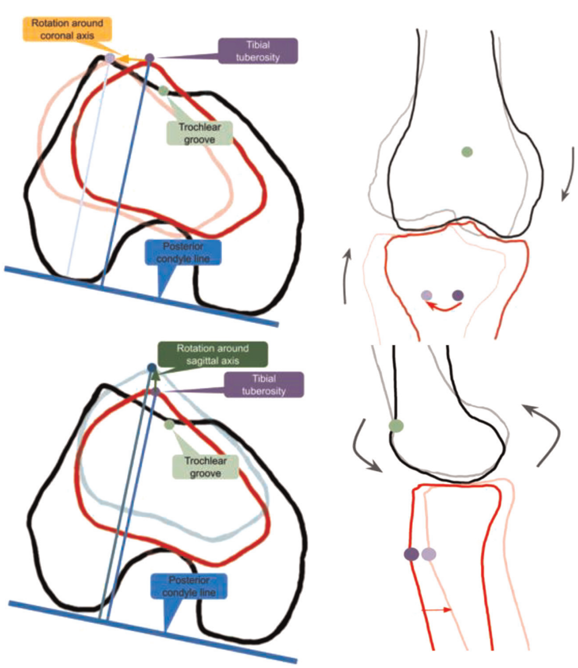

Figure 2. Rotating the whole knee or leg around the coronal axis of the scanner (coronal angle α in Figure 1) moves the tibial tuberosity (TT) (in red) mediolaterally (solid before rotation and transparent after) relative to the trochlear groove (TG) axial slice (black). Rotating the whole knee or leg around the sagittal axis of the scanner (sagittal angle β in Figure 1) moves the TT anteroposteriorly relative to the TG axial slice. The sagittal and coronal rotations affect TT-TG distance differently depending on the posterior condylar line (blue) orientation, with the rotation around the sagittal axis becoming irrelevant if the line is horizontal (see equation 1 with $\gamma = 0$ in Figure 1).

Segmentation and Landmark Placement

Scans were segmented using Simpleware ScanIP software (Synopsys, Inc). Initial segmentation masks and landmarks were created using the CT knee autosegmentation algorithm. One author (A.R.M.), a postdoctoral researcher, reviewed the landmarks and, if necessary, corrected them manually to ensure fidelity to true patient anatomy. A second author (N.P.), a fourth-year medical student doing an orthopaedic research year, redid the same process for a subset for 11 knees, which were used to calculate interrater reliability. Both authors were trained and supervised by the senior author (J.P.F.), a professor of orthopaedic surgery. The autosegmentation algorithm placed most of the required landmarks (see Table 1). The TG landmark was placed manually. Landmarks were placed utilizing the 3D models and the relevant coronal, sagittal, and axial CT images (as explained in Figure 3). The resulting landmark coordinates were then exported to text files for further processing in MATLAB 2023a (Mathworks, Inc).

Algorithm

Two algorithms for calculating TT-TG were developed. The first was used to calculate TT-TG according to the established 2D method by utilizing the SLA (ie, coordinate system given by the Digital Imaging and Communications in Medicine files). The second algorithm was used to calculate TT-TG using the TLA (ie, 3D TT-TG), thus removing the effect of knee positioning within the scanner. Both algorithms used the same landmarks as applicable, reducing the influence of landmark placement on the overall difference results.

The algorithm for 2D TT-TG calculation was as follows:

TABLE 1
3D Landmarks Used in This Study for TT-TG Calculation (see Figure 3) and How They Were Placed[a]

Landmark	Description	Placement
Femoral posterior condyles	Placed on the most posterior point of the femoral condyle (see Figure 3A)	Placed by AI tool and reviewed by author (A.R.M.)
Tibial intercondylar tubercles	Placed on the most prominent point of the lateral and medial tubercles (see Figure 3B)	Placed by AI tool and reviewed by author (A.R.M.)
Tibial shaft center	Placed in the midpoint of an arc fitted around the posterior half of the tibial shaft	Placed by AI tool and reviewed by author (A.R.M.)
Tibial tuberosity	Placed in the center point of the tibial attachment site of the patellar tendon, utilizing the axial and sagittal CT views (see Figure 3, C and D)	Placed by AI tool and reviewed by author (A.R.M.)
Trochlear groove	Placed in the deepest point of the trochlear groove at the height of the transition point as described by Yu et al[24] (see Figure 3E)	Placed by one author (S.T.D.) and reviewed by another (A.R.M.)

[a]3D, 3-dimensional; AI, artificial intelligence; CT, computed tomography; TT-TG, tibial tuberosity–trochlear groove.

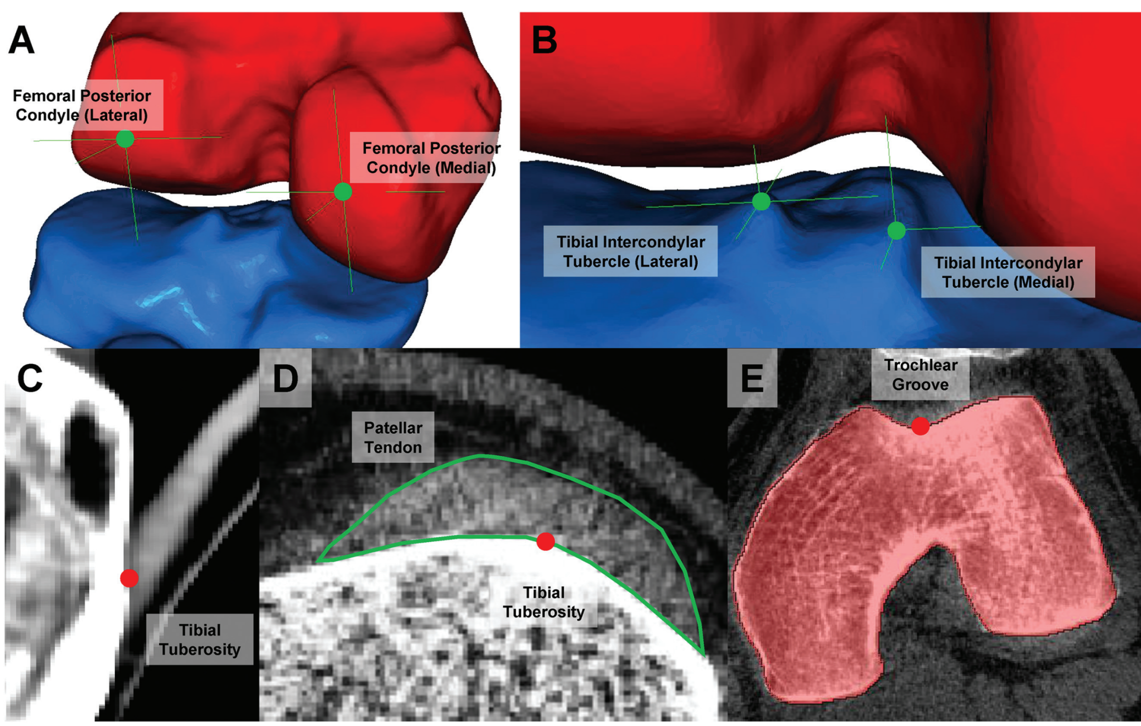

Figure 3. Landmarks (indicated by green and red dots) used in this study. (A) The femoral posterior condylar landmarks were placed at the most posterior point on the medial and lateral condyles. (B) The tibial intercondylar tubercle landmarks were placed on the tibial plateau's most prominent medial and lateral features. The tibial tuberosity landmark was placed using sagittal and axial slices of the computed tomography scan. (C) The sagittal slice was used to determine the superoinferior position. (D) Afterward, the landmark was moved medially or laterally on the axial view to be placed precisely within the middle of the patellar tendon (outlined in green on the axial slice). (E) The trochlear groove landmark was placed in the deepest part of the trochlear groove.

1. SLA was identified, which was in most cases represented by the vector (0, 0, 1).
2. A 3D vector was created connecting the 2 posterior femoral condyles and making it perpendicular to the SLA afterward (ie, a line segment was drawn between the posterior condyles on the axial plane ⟶ 2D posterior condyle line).
3. A vector was created connecting the TT and the TG and making it perpendicular to the SLA.
4. The second 2D vector was projected on the 2D posterior condyle line, and the length of this projected vector was created; that length was TT-TG in the traditional (2D) sense.

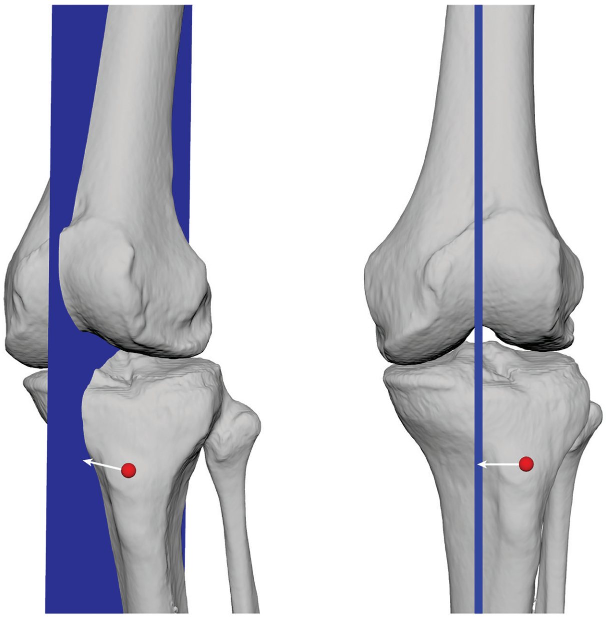

Figure 4. Three-dimensional (3D) tibial tuberosity–trochlear groove (TT-TG) distance calculation can be visualized by first drawing a plane parallel to the tibial longitudinal axis (TLA), oriented by the posterior condylar line, and intersecting the TG (blue). The perpendicular distance between the TT (red dot) and this plane is the 3D TT-TG distance. When the scanner's longitudinal axis and TLA are the same, both algorithms yield the same result.

The algorithm for 3D TT-TG calculation (see Figure 4 for conceptional visualization) was as follows:

1. A 3D vector was created between the tibial shaft center and the midpoint between the intercondylar tubercle landmarks, creating the TLA.
2. A 3D vector was created connecting the 2 posterior condyles and making it perpendicular to the TLA, which was the posterior condyle line.
3. A 3D vector was created connecting the TT and the TG.
4. The resulting vector was projected on the posterior condyle line, and the length of this projected vector was calculated; that length was TT-TG utilizing a 3D reference frame.

Establishing the posterior condyle line as perpendicular to the TLA was necessary because the proximity of posterior points on the condyles varied between the lateral and medial sides, creating a potentially tilted posterior condyle line. Many clinicians and researchers using the 2D method do not account for the condyle's most posterior points being on different axial slices, which introduces another source of discrepancy in 2D TT-TG. This discrepancy was not addressed and quantified within this work but nevertheless adds to the overall difference between 2D and 3D TT-TG in clinical practice. Notably, this discrepancy also changed with coronal knee rotation in the scanner. The 3D method was not influenced by this effect, as landmarks were chosen independently from which axial slice they were on.

Measuring Angular Alignment and Vertical Distance

All angular alignment angles used in the model evaluation were measured with respect to the SLA (see Figure 1).

- Coronal rotation: angle between the SLA projected on the coronal plane and a line between intercondylar tubercles and the tibial shaft center.
- Sagittal rotation: angle between the SLA projected on the sagittal plane and a line between intercondylar tubercles and the tibial shaft center.
- posterior condyle line angle: angle between the posterior condyle line and the sagittal axis.

The code used to calculate 2D TT-TG, 3D TT-TG, the angles, and the vertical distance is available online.[18]

Model for Difference Estimation

A model, based on the equation 1 displayed above, was constructed to describe the estimated difference between 2D and 3D TT-TG. For simplicity, the model presented here used the inferosuperior distance measured between the TG and the TT (ie, d_z) measured within the scanner coordinate system. This model can be used for estimating the difference between 2D and 3D TT-TG for small rotation around the 2 axes (eg, angles of $<20°$, allowing for the simplification sin(angle) = angle/180 * π). The factors k_1 and k_2 were calculated using a linear regression model in MATLAB R2023a.

Equation 2:

$$\mathit{Difference} \approx d_z * \left(\frac{k_1}{100} * \alpha * \cos(\gamma) + \frac{k_2}{100} * \beta * \sin(\gamma)\right) \quad (2)$$

Distances are in millimeters and angles in degrees. The coefficients in this model can be estimated as follows:

$$k_{1,2} \approx 100 * \frac{\pi}{180} = 1.74$$

The real values k_1 and k_2 were assumed to be slightly higher due to simplifying the distance between the TG and TT.

Statistical Analysis

After completing the measurements for the initial sample set of 40 knees, we performed a power analysis for sample size calculation for the statistical tests comparing 2D and 3D TT-TG described below (ie, test for means and variance). The higher sample size obtained was used to select the sample size for this study. A power level of 0.80 was used.

The means, standard deviations, and range of 2D and 3D TT-TG and their differences were calculated. The root mean square (RMS) differences were calculated. The significance of differences between 2D and 3D TT-TG was tested using a Student *t* test, after testing for normal distribution using a Jarque-Bera test. The difference in variances between 2D and 3D TT-TG was calculated via *F* test. Significance for all tests was assumed at .05.

TABLE 2
Means, SDs, and Differences in Measured TT-TG for 2D and 3D Methods[a]

Group	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	RMS
	2D TT-TG, mm		3D TT-TG, mm		2D vs 3D differences, mm		
Patient Knees (N = 44)	19.8 ± 7.2	7.2 to 41.0	17.1 ± 4.9	6.7 to 28.3	2.7 ± 4.1	–4.0 to 14.7	4.8
	Coronal Rotation, deg		Sagittal Rotation, deg		Posterior Condylar Line Angle, Deg		
	2.3 ± 5.2	–9.4 to 16.6	–1.7 ± 7.5	–14.5 to 17.4	–6.9 ± 13.3	–38.2 to 27.8	NA

[a]The mean (*P* = .045) and the variance (*P* = .012) of the TT-TG in 2D are significantly higher than those measured in 3D. The mean, SD, and range are given for the deviation of the TLA from the scanner coordinate system in the coronal and sagittal planes and for the posterior condylar line from the axial horizontal line. 2D, 2-dimensional; 3D, 3-dimensional; RMS, root mean square; TT-TG, tibial tuberosity–trochlear groove.

Interrater reliability was calculated via a single measurement method, the 2-way random intraclass correlation coefficient (ICC[A,1]). The ICC value was evaluated according to existing literature.[11] The mean, standard deviation, and range for the leg-scanner alignment angles were calculated.

The reliability of the model was tested by calculating the RMS error, t statistic, and adjusted r^2 value. The P value for the coefficients and their confidence interval was calculated. P values of $<.05$ were regarded as significant. All statistics were calculated in MATLAB R2023a.

RESULTS

The power calculation yielded a minimum sample size of 44 knees (a minimum of 26 for variance and 44 for difference in means) for a power level of 0.8. In total, 44 patient knees were selected, and corresponding landmark data sets were analyzed. Patient knees were acquired from 40 individual patients (sex: 27 female, 13 male; mean ± SD age: 26.2 ± 11.5 years) from 42 individual scans. Differences ranged from –4.0 mm (2D was smaller than 3D TT-TG) to 14.7 mm, with mean 2D TT-TG being significantly larger for patient scans (*P* = .045) (Table 2). The RMS difference was 4.8 mm. With the 2D measurement, 17 (38.6%) knees were over the threshold of 20-mm TT-TG; with the proposed 3D metric, 10 (22.7%) knees were over the threshold. The variance of the 3D method was significantly lower than that of the 2D method (*P* = .005). The ICC of the 3D measurement method was 0.94 with a 95% CI of 0.81 to 0.98.

Table 2 shows how much the longitudinal axis deviated from the scanner axis for both sample groups. On average, the posterior condyle line was rotated externally relative to the horizontal line on the scan. The tibia was rotated outward coronally on average by 2.3°, leading to the mean 2D TT-TG being larger than the mean 3D TT-TG in both groups. The posterior condyle line angle in knees was on average negative. The wide range of differences was caused by the wide range of the measured angles listed in Table 1. A total of 13 (29.5%) of the knees had a difference of >5 mm between 2D and 3D TT-TG.

The values k_1 and k_2 from equation 2 were calculated with a linear regression model using the measured 2D and 3D TT-TG values. The results of this model are shown in shown in Table 3. The model coefficients k_1 and k_2 were calculated to be 1.82 and 1.80, respectively. The coefficients led to the following model to estimate the difference:

Equation 3:

$$Estimate \approx d_z * \left(\frac{1.82}{100} * \alpha * \cos(\gamma) + \frac{1.80}{100} * \beta * \sin(\gamma)\right)$$

Because k_1 and k_2 are approximately the same, this can be simplified to

$$\approx \frac{d_z * 1.8}{100} * (\alpha * \cos(\gamma) + \beta * \sin(\gamma))$$

$$d_z \ldots \textit{Vertical Distance TT to TG on Scan}$$

$$\alpha, \beta, \gamma \ldots \textit{Coronal, sagittal, and posterior condyle line rotation (see Figure 1)} \quad (3)$$

DISCUSSION

This study found significant differences between TT-TG measured via the standard 2D method and TT-TG measured via a 3D method not dependent on the knee being correctly aligned within the scanner. The statistical evaluation of the model shows that these differences are almost perfectly (adjusted r^2 value $\approx$ 1) explained by the axial and coronal rotations of the tibia. This highlights the need to consider the critical importance of knee alignment in the scanner when measuring TT-TG. Two-dimensional TT-TG was, on average, 2.7 mm larger, with an SD of 4.1 mm, than values from 3D TT-TG calculations, with differences reaching up to 14.7 mm and 29.5% of the knees having a difference of >5 mm. The variance of TT-TG measured using the 3D method was significantly lower than that of 2D TT-TG, suggesting that the 3D method is more stable and less influenced by external factors.

The 3D method's reliability can be considered good to excellent,[11] and we deem it therefore adequate for clinical practice. Nevertheless, it requires the creation of 3D surface models for each scan, which makes its widespread implementation currently unrealistic as this image-processing capability is not widely available for clinical

TABLE 3
Coefficients for Estimating the Difference Between 2D and 3D TT-TG[a]

N = 44 Group	Coefficients		Statistics for Model Validity			
	k_1 (95% CI)	k_2 (95% CI)	t Statistic k_1/k_2	P Value k_1/k_2	RMS	Adjusted r^2
Patient Knees	1.82 (1.80-1.85)	1.80 (1.73-1.88)	141/51	<.001	0.21	1.00

[a]2D, 2-dimensional; 3D, 3-dimensional; RMS, root mean square; TT-TG, tibial tuberosity–trochlear groove.
Coefficients were calculated according to the measured leg alignment angles and corresponding differences in 2D and 3D TT-TG via linear regression.

use. However, artificial intelligence–based autosegmentation and landmark placement algorithms are becoming increasingly more accurate and have already played an important role in enabling this study. Still, human input was necessary to place the landmark in the TG and ensure the accuracy needed for the measurement method. It is reasonable to assume that sufficiently sophisticated artificial intelligence algorithms, which can place all landmarks and are sufficiently reliable, will be developed in the relatively near future. Until then, we suggest that findings with the 3D TT-TG method, rather than the traditional 2D method, should be employed in research and to evaluate the consistency of knee placement in radiology centers. Meanwhile, clinicians should exercise considerable caution in decision-making based on 2D TT-TG measurements

This study was conducted using CT scans, but the issue's root cause (ie, alignment of the knee in the scanner) is a geometrical phenomenon and can occur regardless of imaging modality. In current clinical practice, MRI scans are more ubiquitous in the evaluation of patellar instability. For example, lower TT-TG measurements on MRI compared with CT scans have been cited as due to the relative varus positioning in MRI,[4,9,10] causing different alignment angles between SLA and TLA. Still, even though the results in this study are only applicable for CT scans at our institution, the model discussed here is, theoretically, fully transferable to 3D models generated using MRI scans.

In addition to the alignment factor described in this study, TT-TG is known to be less in flexion than in full extension,[21] with a mean change of 5.7 mm between 5° and 30° of flexion. Other studies have linked this to the known reduction in tibiofemoral rotation when the knee is flexed.[2,25] This tibiofemoral rotation is another factor of uncertainty in TT-TG measurement. A recent study[16] showed that this rotation is not constant between scans and can change TT-TG even when applying the same protocol and measurement method (−3.8 to 8.8 mm).

We suggest 3 steps to minimize the error caused by leg alignment, flexion, and tibiofemoral rotation. First, physicians, surgeons, and radiologists should be aware of these issues associated with leg position in the scanner. Second, radiology centers might consider implementing standardized protocols for consistent leg placement, taking the findings of all these studies into account. Third, radiologists and surgeons have to be able to detect and ideally correct these errors even after the scan has been taken. In case of the alignment issue outlined in this study, we suggest that reformatting (regenerating a CT scan according to a new coordinate system) can play a major role. It could be used to correct for malalignment of a leg in the scanner after a scan is taken. Still, we are not aware of a verified and reliable reformatting protocol for TT-TG. Reformatting might seem trivial initially, but the dependence of TT-TG on multiple axes and the difficulty of choosing reliable landmarks in 2D could make such a protocol unreliable, creating a need for further research in this area.

Given the unreliability of current 2D TT-TG measurements,[2,16,21,23] we posit that the dominance of TT-TG in surgical decision-making should be questioned.[20] Therefore, we advocate for adopting a holistic approach putting more emphasis on physical examination, 3D trochlear morphology,[3,24] patella alta, and soft tissue constraints,[17] in addition to 2D TT-TG.

Limitations

The PFI scans selected for this study were all from patients treated by a single physician at a single institution. Therefore, this study was only able to show the existence of the previously described alignment effect[23] on TT-TG in the clinical setting but was not able to quantify its magnitude and prevalence across institutions and radiological centers. This study retrospectively compared the differences between 2D and 3D TT-TG measurements on single patient scans and did not control for scanner-leg alignment prospectively. Therefore, we are not able to quantify how a protocol putting emphasis on correct leg-scanner alignment would reduce the difference between 2D and 3D TT-TG. In addition, we did not carry out 2D[23] and 3D measurement in subsequent scans of the same knee with different scanner-leg alignments.

Compared with the 2D method of measuring TT-TG, the 3D method utilizes 3 more landmarks (tibial intercondylar tubercles and the tibial shaft center) to calculate the TLA. Depending on which landmarks are used and how those are identified, the orientation of the TLA would change, thus influencing 3D TT-TG. The selected landmarks seem intuitively reasonable and provide good to excellent reliability but might misrepresent the actual leg alignment and its associated error. All other landmarks were used for both 2D and 3D TT-TG and would not introduce additional error.

This study did not correlate patient outcomes with the differences between 2D and 3D TT-TG. Therefore, we cannot estimate whether any adverse effects would be associated with the current 2D metric.

CONCLUSION

Three-dimensional TT-TG can be used to correct scanner-leg alignment errors, some of which are substantial when using only 2D TT-TG measurements. The findings in this study suggest a need for caution and awareness of the potential effects of differences in alignment of the axes of the leg and scanner when using purely 2D TT-TG as a basis for surgical planning.

ACKNOWLEDGMENT

The authors thank the Yale Department of Orthopaedics & Rehabilitation for supporting this research.

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