Tibial Tuberosity to Trochlea Groove Distance (TT-TG): A Patellar Instability Gold Standard Prone to Errors?

Johannes Sieberer [1], Nancy Park [1], Albert Rancu [1], Armita Manafzadeh [1], Daniel Wiznia[1], John Fulkerson [1]
[1]Yale University, New Haven, CT
Johannes.sieberer@yale.edu

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INTRODUCTION: For decades, trochlea groove to tibial tuberosity (TT-TG) distance has been the gold standard for clinical decision-making in patellar instability. Therefore, the accuracy of the metric has large implications for patient care. Numerous studies and reviews have pointed out potential sources of measurement error in TT-TG, such as differences in landmark selection, flexion of the knee while measuring, and axial alignment of the knee in the scanner. Most studies have reported high interrater reliability (IRR) for landmark selection to justify using TT-TG as a clinical metric without detailing errors within the scan. These errors, such as axial alignment of the knee, occur because TT-TG simplifies a three-dimensional (3D) feature using a two-dimensional (2D) measurement. To date, no studies have analyzed how these simplification errors translate into clinical practice. In this study, we developed a 3D method to quantify the discrepancy between classic TT-TG measured in 2D (2D TT-TG) and the true TT-TG measured in 3D (3D TT-TG). In addition, we quantify the change in measured TT-TG depending on whether the most proximal, the most distal, or an intermediate point in the trochlear groove is chosen.

METHODS: High resolution CT scans of 20 patients with lateral PF instability and of 20 control knees from the New Mexico Decedent Image Database were segmented, and 3D models created. The femoral posterior condyles, proximal, middle, and distal trochlea groove, tibial shaft center, and tibial intercondylar tubercles were marked on each model. These landmarks are the base for a 3D TT-TG measurement analogous to TT-TG measured on axial CT slices. 3D TT-TG distance was measured perpendicular to the longitudinal tibial axis (chosen to minimize the influence of Q-angle and, therefore, gender) and the corresponding posterior femoral condyle line for all 3D models. 2D TT-TG was measured perpendicular to the posterior condyle line on axial slices, using the same landmarks as true TT-TG. In addition, the coronal angle between the tibia longitudinal axis and the corresponding axis of the scanner was calculated. TT-TG measurements were carried out for the most proximal and most distal points as well as the midpoint of the trochlear groove. Significant differences between patients and controls were analyzed with a Mann-Whitney U test. P-values of less than 0.01 were considered significant to account for multiple hypotheses testing. Differences between 2D and 3D TT-TG were correlated with Pearson coefficients. The study was regarded as exempt by the institutional review board.

RESULTS SECTION: Table 1 summarizes the results for 2D TT-TG and 3D TT-TG, their differences, and the corresponding alignment angle. In some patients, the trochlear groove is curved, causing variation in 2D and 3D TT-TG, reducing TT-TG of up to 11.3 mm (3.2±3.6 TT-TG) when measuring the most proximal point of the trochlea compared to the most distal point or midpoint of the trochlear groove. In controls, the maximum reduction was 5.8 mm (1.5±1.2 mm). 2D and 3D TT-TG significantly differed between patients and controls ($p < 0.01$). Angular malalignment was not significantly different between patients and controls ($p = 0.603$). Patients' trochleae were significantly more curved than controls. Patients' difference between 2D and 3D had a correlation R-value to angular malalignment of 0.85 ($p < 0.01$) (controls R-value: 0.88 p-value < 0.01).

DISCUSSION: The current 2D method of measuring TT-TG (2D TT-TG) is strongly influenced by the orientation of the patient's knee in the scanner. For nearly one-third of patients, the error resulting from orientation changes was more than 5 mm, in other words, more than the mean difference between the patient and control group. Differences between 2D and 3D TT-TG were significantly correlated with scanner-tibia alignment. Knees that were correctly positioned within the scanner showed minimal differences between 2D and 3D TT-TG, showing that the current method of measuring TT-TG can be used in clinical practice if a robust radiological protocol is in place to make sure the tibial axis is properly aligned within the scanner. However, due to the significant difference between 2D and 3D TT-TG population values and the inconsistent thresholds defined in studies without exclusion criteria for patient knee alignment, the use of TT-TG must be reevaluated. Variation of the proximity of the point within the trochlea can cause differences in TT-TG of more than 10 mm, with the use of a proximal point reducing TT-TG. Universal agreement on where to measure is necessary to achieve a standard in clinical decision-making; with choosing a distal point reducing error and variation overall. Due to current limitations of the sample, we cannot estimate error prevalence yet.

SIGNIFICANCE/CLINICAL RELEVANCE: This study shows that the radiological metric TT-TG, the cornerstone of clinical decision-making in patellar instability, is susceptible to errors caused by patient-scanner alignment. Robust radiological protocols can be used to minimize this error.

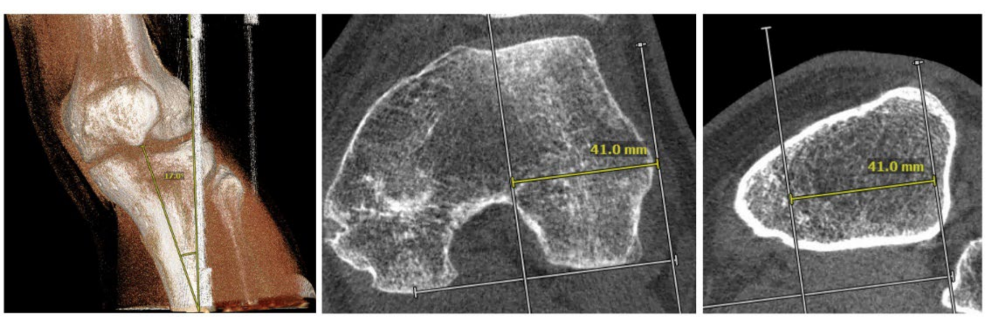

Figure 1: Greyscale rendering of patient scan (left) with the largest angular malignment between the scanner and patient's knee (~17 degrees) and corresponding TT-TG measurement (middle and right). The patient had a 2D TT-TG of 41.0 mm and 26.6mm in the 3D version. The difference is caused by the rotation. Differences between 2D and 3D methods become minimal when the malalignment between the scanner and the knee is close to zero.

Table 1: Patient and control knees showed significant differences between 2D and 3D TT-TG (*). Errors are significantly correlated with angular alignment (+).

	TT-TG measured on axial slices (2D TT-TG) in mm		TT-TG measured in 3D (3D TT-TG) in mm		Difference between in 2D TT-TG and 3D TT-TG in mm			Angular malignment between scanner and patient's knee in degree		
Group	Min-Max	Mean±Std	Min-Max	Mean±Std	Min-Max	Mean±Std	>5 mm	Min-Max	Mean±Std	>5degree
Patients	10.8-41.0	21.4±7.5*	8.6-26.3	16.9±4.2*	-2.4-14.4+	3.6±4.1	30% (6/20)	-7.7-17.2+	3.9±5.4	40% (8/20)
Controls	7.0-22.6	15.7±4.1*	7.3-16.4	12.9±2.6*	-1.5-8.3+	3.0±3.0	15% (3/20)	-3.6-15.4+	3.5 ±4.6	40% (8/20)