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Original Research

Breaking down tibial tuberosity to trochlear groove distance into two components to enable patient-specific treatment strategies

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ABSTRACT

Objective: Tibial tuberosity to trochlear groove (TT-TG) distance serves as one of the main metrics for patellofemoral instability (PFI) surgical decision-making. The purpose of this study is to split TT-TG into translational (caused by bony morphology) and rotational (external tibiofemoral rotation) components, elucidate how those two components relate to each other, and determine how the components differ between recurrent PFI patients and controls.

Methods: Computed tomography (CT) scans of PFI patients with at least two reported dislocation events, seen by our institution's orthopedic department, were retrospectively acquired. Control CT scans were acquired from the Multicenter Osteoarthritis Study (MOST). Three-dimensional (3D) landmarks were placed on the distal femora and the proximal tibias. TT-TG, its rotational and translational components, and tibiofemoral rotation were algorithmically calculated from these landmarks. The two cohorts' means were compared using Mann–Whitney U-tests. Pearson coefficients were used to evaluate the correlation between the TT-TG components. The reliability of the measurements was evaluated with intraclass correlation coefficients (ICCs). The minimal sample size for a power level of 0.80 was calculated with an *a priori* sample size calculation.

Results: A total of 26 PFI (sex parity; age: 24.6 ± 10.0 years) and 294 control knees (sex parity; age: 52.6 ± 7.0 years) were analyzed. Statistically significant differences for TT-TG (18.7 ± 4.8 vs. 12.0 ± 3.4 mm, $p < 0.001$), rotational (5.3 ± 2.5 vs. 1.0 ± 2.5 mm, $p < 0.001$) and translational (13.4 ± 3.7 vs. 11.0 ± 3.1 mm, $p = 0.002$) components of TT-TG, and tibiofemoral rotation (10.7 ± 4.7 vs. 1.9 ± 4.7°, $p < 0.001$) were found. No significant correlation between the components of TT-TG was found ($p = 0.14$, $r^2 = 0.29$). Predictive ICCs for the four measurements ranged from 0.82 to 0.99.

Conclusion: TT-TG can be split into (1) a translational component, primarily dependent on bony morphology, and (2) a rotational component, caused by external tibiofemoral rotation, both of which can lead to an elevated TT-TG measurement independently of each other. The rotational component is the primary factor for differences observed between PFI patients and controls but might vary between consequential patient scans. Our findings emphasize the importance of personalized treatment strategies tailored to individual patient profiles in treating patellar instability and will aid in more accurately targeted selection of surgical methods addressing either or both translational or rotational components of TT-TG.

Level of evidence: III Case-Control study.

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What are the new findings?

- Tibial tuberosity to trochlear groove distance (TT-TG) can be split into a rotational and bone morphology component.
- The rotational component is the main driver of elevated TT-TG.
- The independence of components indicate different patient groups.

INTRODUCTION

Tibial tuberosity to trochlear groove (TT-TG) distance serves as one of the main metrics clinicians use to understand how a patient's osteological morphology leads to patellofemoral instability (PFI). This metric serves as an indicator of the lateral component of the patellar force vector, and when elevated, increases the risk of lateral patellar subluxation and patellofemoral osteoarthritis [1,2]. It is conceptually possible to separate TT-TG into two components (1) a fixed morphological (i.e. translational): component, and (2) a variable rotational component (shown in Fig. 1). The translational component depends on fixed elements of bony morphology, specifically lateralization of the TT on the proximal tibia and medialization of the TG on the distal femur [3–7]. By contrast, the rotational component varies with tibiofemoral rotation [8] (rotation of the tibia in relation to the femur along the anatomical axis) as caused by bony morphology, laxity or absence of soft tissue constraints, or the state of the patient's leg in the scanner (weightbearing, flexion, or torque on the tibia around the longitudinal axis). Many surgical solutions for reducing TT-TG, such as tibial tubercle osteotomies, target morphological modification of the translational component, while others, such derotational osteotomies, target the rotational component. Therefore, a separation of those two components would assist in deciding which surgical tool to choose.

Conventional TT-TG measurements can be prone to alignment errors based on leg positioning and choice of the axial slice of computed tomography/magnetic resonance imaging (CT/MRI) from which the measurement is taken [9–11]. As a result, there is increasing interest in measuring TT-TG from three-dimensional (3D) models to obviate these errors [12]. In this paper, we present an extension of an existing 3D method [11] to separate 3D TT-TG into components due to osteological morphology versus tibiofemoral rotation. In addition to presenting this 3D method, the purpose of this study is to begin to unravel the interplay between translational and rotational TT-TG in both patients with recurrent patellar instability and controls. We hypothesize that between these populations, translational and rotational TT-TG are significantly higher in patients, but that knees with high TT-TG do not necessarily have simultaneously high rotational and translational TT-TG.

METHODS

This study was conducted according to the STROBE [13] statement, and the completed checklist was provided to the journal. This study was deemed exempt by our institutional research board (Yale University IRB) and can be found under correspondence number 2000035572.

Dataset acquisition

Our institution's medical image database was retrospectively queried for patients seen by our institution's orthopedic department between 2021 and 2024, at least 14 years old at the time of imaging, with at least two patellar dislocation events, and possessing a high-resolution CT scan. Patient scans were excluded if the knee was not in full extension or if the joint was not fully ossified. Treatment selection and follow-up data were not analyzed in this study. Controls were acquired from the Multicenter Osteoarthritis Study (MOST) [14]. The MOST is a National Institutes of Health (NIH)-funded cohort study of persons aged 45 and over with or at risk of knee osteoarthritis. Included controls had no recurrent PFI at the time of the study or previous surgical procedures for PFI. Although unlikely, controls could have had previous patellar dislocations. Every participant underwent standardized high-resolution CT during the study. For this study, we acquired a sample set of 294 patients aged 45–55 years, with and without patellofemoral osteoarthritis (OA). Sex matching was achieved by randomly removing controls from the more prevalent sex until parity with the patient cohort was achieved. The patient and control cohort were not age-matched. An initial dataset from these two cohorts was selected for an *a priori* power calculation. The patient population for interrater reliability calculation (n = 11) and

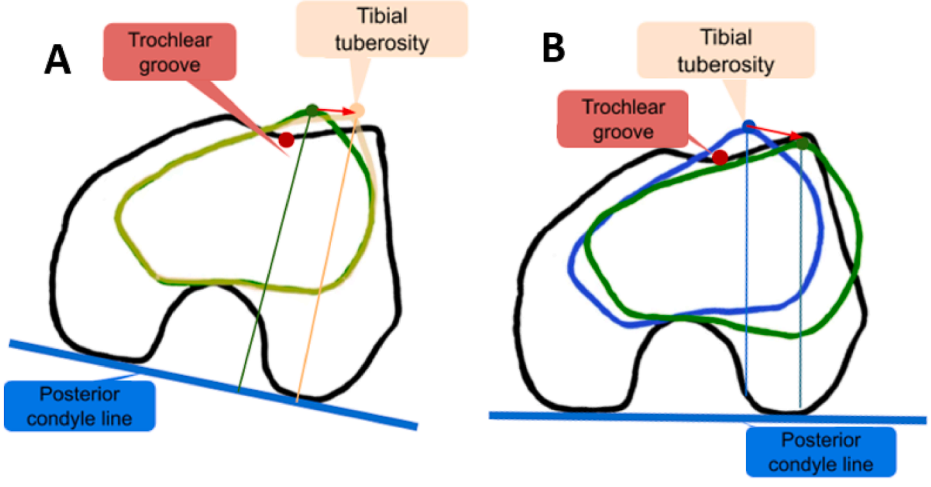

Fig. 1. TT-TG can be higher due to morphological features of the femur (i.e. medialized trochlear groove) and the tibia (lateralized tuberosity) or due to the position of the tibia in relation to the femur, mainly influenced by tibiofemoral rotation. (A) shows how a more lateralized tibial tuberosity (in beige), and (B) shows how external tibiofemoral rotation can cause higher TT-TG (red arrow). TT-TG = tibial tuberosity to trochlear groove.

the full control cohort were used for sample size calculation. To mitigate bias, the authors involved in data acquisition were not involved in the diagnosis of patients and selection of controls.

3D segmentation and landmark placement

The CT scans were segmented with Simpleware ScanIP (Synopsis, Inc., Sunnyvale). Anatomical landmarks were placed on the femur and tibia (see Fig. 2) and their 3D coordinates were exported as comma-separated value (CSV) files. This process was aided by ScanIP's auto-segmentation algorithm and manually reviewed and improved by a researcher (A.R.M.), a postdoctoral anatomist. This process was executed for the specified landmarks according to Park. et al. [15]. For a subset of control and patient knees, an additional landmark sample set was created by a second researcher (J.M.S.), a doctoral student in mechanical engineering and orthopedics. Both researchers were trained by the senior author (J.P.F.). The landmarks were the trochlear groove, tibial tuberosity, tibial and femoral posterior condyles (medial and lateral), intercondylar tibial tubercles (medial and lateral), and tibial shaft center (see Fig. 2).

Calculation of 3D, rotational, and translational TT-TG

3D TT-TG was calculated utilizing a previously presented algorithm [11,16] (Note: The functionality of this algorithm is further explained in subsection 3D TT-TG below). This existing algorithm was modified to include rotational and translational TT-TG. Briefly, the algorithm calculates how high TT-TG would be if there was no external tibiofemoral rotation present (translational TT-TG), making it possible to split TT-TG into its components. A conceptual overview of the algorithm is presented below, with the full algorithm available open source in a dedicated code repository [17].

3D TT-TG

TT-TG is conventionally measured on two 2D axial slices by measuring the horizontal distance between the tibial tuberosity and the trochlear groove, parallel to the femoral posterior condyle line (FPCL). When this method was developed, the authors assumed that the knee axis was aligned with the long-axis of the scanner. Recent literature [10, 11] has shown that this is not necessarily the case, which introduces an error into TT-TG measurements. In contrast, measuring 3D TT-TG reduces that error by aligning the image axes with the knee axes, similarly to multiplanar reformatting (MPR). If the knee is already perfectly aligned, there is no difference between conventional (2D) TT-TG and 3D TT-TG [11].

Translational TT-TG

Translational TT-TG captures the component of TT-TG due to lateralization of the TT and medialization of the TG. It is calculated as the sum of these two subcomponents. The TG medialization is calculated by measuring the distance between the tibial eminence and the TG, parallel to the FPCL, and TT lateralization by measuring the distance between the TT and the tibial eminence, parallel to the tibial posterior condyle line (TPCL). A brief description of the measurement of the two subcomponents of translational TT-TG follows below.

Lateralization of the TT (TTL)

1. Create the TPCL by drawing a line from the lateral to the medial posterior tibial condyle.
2. Project the TPCL to be perpendicular to the tibial long-axis (TLA) and create a plane collinear on the TLA and perpendicular to the projected TPCL.
3. Measure the perpendicular distance from the TT to this new plane. This is the TTL distance.

Medialization of the TG (TGM)

1. Create the FPCL by drawing a line from the lateral to the medial posterior tibial condyle.
2. Project the FPCL to be perpendicular to the TLA and create a plane collinear on the TLA and perpendicular to the projected FPCL.
3. Measure the perpendicular distance from the TG to this new plane. This is the TGM distance.

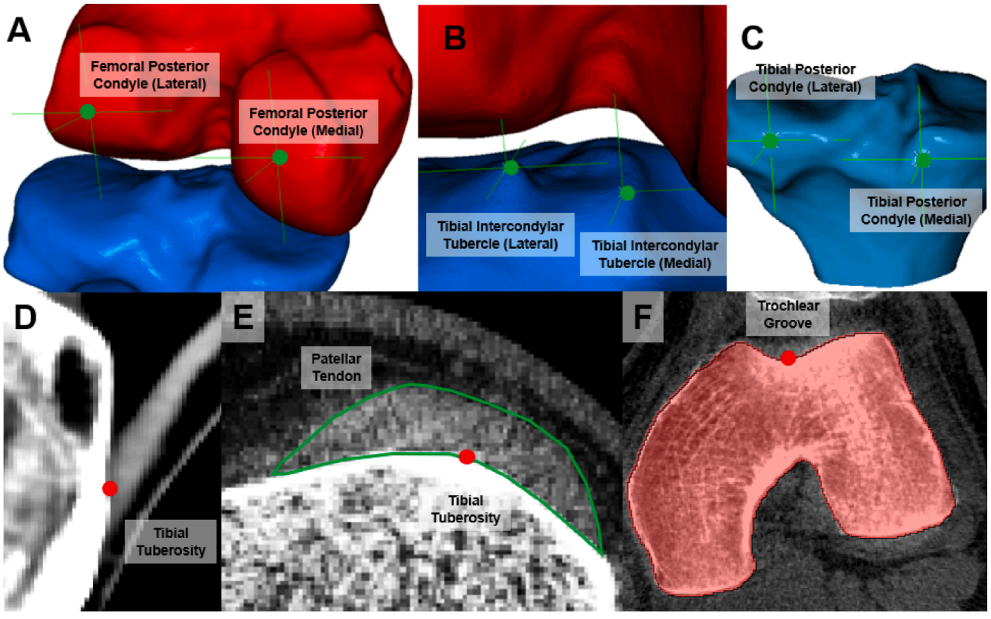

Fig. 2. The landmarks for TT-TG calculation were placed using segmented 3D models and the axial and sagittal slices of the CT scans. (A, B, & C) shows landmarks placed on the 3D models, (D & E) show that the tibial tuberosity was specified as the middle of the patellar tendon attachment site, (F) shows the landmark in the trochlear groove placed at its deepest part at the height of the transition point as specified by Yu[27]. In total, nine landmarks were placed in the segmentation software. 3D = three-dimensional; CT = computed tomography; TT-TG = tibial tuberosity to trochlear groove.

Calculation of the rotational component of TT-TG and tibiofemoral rotation

Rotational TT-TG measures how much TT-TG increases due to tibiofemoral rotation and is therefore equivalent to the difference between translational TT-TG and 3D TT-TG. Tibiofemoral rotation is acquired by calculating the angle between the FPCL and the TPCL along the TLA, with external rotation defined as positive.

Data analysis and statistical methods

An *a priori* sample size calculation for a minimal power of 0.80 was conducted with initial values for all statistical mean tests, and the highest minimal sample size selected. The sample size was the highest for translational TT-TG (13.5 ± 3.3 vs. 12.0 ± 2.5 mm) with a minimal sample size of 26 patients when using at least 250 controls. Demographic differences between patients and controls were evaluated via a Mann–Whitney U test (age) and a Fisher's exact test (sex ratio).

Differences in means and variance between the patient and control group for 3D, translational, and rotational TT-TG, as well as tibiofemoral rotation were tested via a one-tailed Mann–Whitney U test and F-tests after testing for normal distribution via a Jarque–Bera test (significance as $p < 0.05$). The control cut-off value for the 81% percentile for 3D, translational, and rotational TT-TG were calculated, and patients allocated accordingly. The 81% was selected to achieve a 3D TT-TG cut-off value of around 15 mm.

Disaggregated results were provided per sex assigned at birth for all measurements conducted within this study. Differences from controls were tested with a two-sided Mann–Whitney U test. Sex differences between patients were not tested due to the small sample size.

Correlation between patients' translational and rotational TT-TG was calculated using Pearson correlation coefficients.

A linear regression model was calculated to evaluate the relationship between tibiofemoral rotation and rotational TT-TG. The coefficient and its confidence interval, the p-value, the root mean square error (RMSE), and the adjusted r-squared value were calculated for both groups.

Interrater reliabilities of translational and rotational TT-TG were calculated using a subsample of 11 patient and 20 control knees, each with two raters, using single measurement, two-way random interclass correlation coefficients (ICCs (A,1)) and evaluated according to existing literature [18]. All statistics were calculated in MATLAB R2023b. For all testing, statistical significance was assumed at $p < 0.05$.

The calculation of all metrics presented in this study was carried out by the first author (J.M.S.). This author was not involved in the landmark acquisition used for comparing patients and controls and was the only person who had access to the output data until data collection was finished. This was done for blinding purposes. Outlier data (e.g. switched landmarks) were reported back to the postdoctoral researcher for verification and corrected if necessary.

RESULTS

A total of 40 patient knees fit the inclusion criteria, of which 14 knees were excluded (4 knees not fully ossified and 10 knees were not fully extended). From 294 control knees, 17 females were removed to achieve sex matching. This led to a total of 26 included patient knees from 25 patients with recurrent PFI and 277 control knees. We measured 3D, translational, and rotational TT-TG values and tibiofemoral rotation for each knee. No patient or control knee was excluded due to missing data. The randomly removed control knees from the initial control cohort led to a slight increase of TT-TG mean (0.05 mm) and standard deviation (0.02 mm) within the control cohort. This increase was due to women generally having lower TT-TG than men.

Means differed significantly between the patient and control groups for 3D (18.7 vs. 12.0 mm, $p < 0.001$), rotational (5.3 vs. 1.0 mm, $p < 0.001$), translational TT-TG (13.4 vs. 11.0 mm, $p = 0.002$), and tibiofemoral rotation (10.7 vs. 1.9 deg, $p < 0.001$). Variance differed significantly for 3D (standard deviation [STD]: 4.8 vs. 3.4 mm, $p = 0.003$) and translational (STD: 3.7 vs. 3.1 mm, $p = 0.003$) TT-TG between the patient and control groups. No statistically significant differences were found for variance in tibiofemoral rotation ($p = 0.72$) or rotational TT-TG ($p = 0.81$). In the control cohort, statistically significant sex differences were found for 3D TT-TG (M/F: 12.4 vs. 11.6 mm, $p = 0.029$), translational TT-TG (M/F: 11.7 vs. 10.4 mm, $p < 0.001$), and tibiofemoral rotation (M/F: 1.4 vs. 2.4 deg, $p = 0.045$), but not for rotational TT-TG (M/F: 0.8 vs. 1.2 mm, $p = 0.11$). The distribution of indivdual values can be found in Fig. 3.

Twenty-one patients were over the 15 mm cut-off for TT-TG, of which 11 had only high rotational TT-TG, 2 had only high translational TT-TG, and 8 had both high rotational and high translational TT-TG (see Table 1).

No correlation between rotational and translational TT-TG was found ($p = 0.14$, $r^2 = 0.29$). The linear regression model for correlation between tibiofemoral rotation and rotational TT-TG showed significance (adjusted r-squared: 0.86, see Table 2). In the full dataset, one degree of tibiofemoral rotation caused approximately 0.49 mm of rotational TT-TG.

Interrater reliability for translational TT-TG can be regarded as moderate to good, and all others are at least good to excellent (detailed values are listed in Table 2).

DISCUSSION

In this study we adapted an existing algorithm to measure TT-TG based on 3D landmarks, split TT-TG into two components (i.e. translational and rotational TT-TG), and applied this modified algorithm to both patient and control cohorts. The main findings are: (1) both translational and rotational TT-TG are higher in patients with PFI, (2) there is no significant correlation between translational and rotational TT-TG, and (3) tibiofemoral rotation must be acknowledged as a

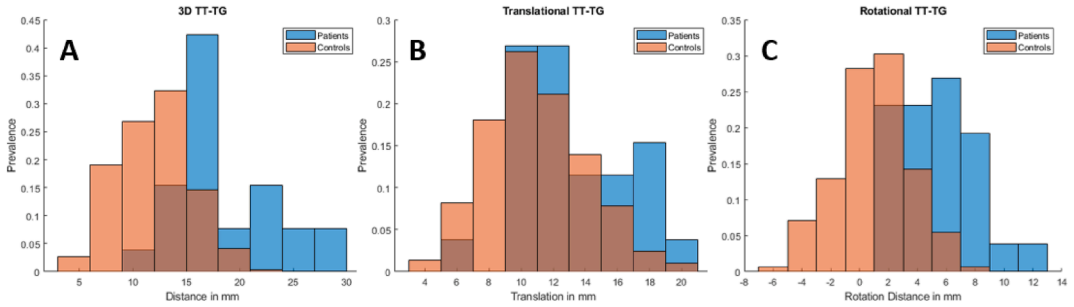

Fig. 3. Distribution of 3D TT-TG (A), translational component of TT-TG (B), and rotational component of TT-TG (C) for patients (blue) and controls (orange). In all histograms, the patients' distribution is shifted toward higher values (right) compared to controls as noted in Table 1. However, in all three subplots, there is overlap between controls and patients, highlighting that TT-TG, even when separated into its subcomponents, is not the only relevant metric for understanding PFI.

Table 1
Mean and standard deviation for the metrics measured in this study. Statistically significant differences are shown in bold. The number of patients over the 81% percentile cut-off values of the control cohort for 3D, rotational, and translational TT-TG. Knees that exceeded both thresholds for rotational and translational TT-TG were listed separately from those that exceeded only one.

Demographics per cohort						
Demographics	Patient knees (n = 26)		Control knees (n = 294)		Statistical test	p-value
Sex (F/M)	13	13	147	147	Fisher's exact test	1.00
Age (in years)	25.8 ± 11.7	23.8 ± 8.6	52.3 ± 7.2	52.7 ± 6.7	Mann–Whitney U	**<0.001**

Measurement results per cohort								
Measurement	3D TT-TG/mm		Rotational TT-TG/mm		Translational TT-TG/mm		Tibiofemoral rotation/deg	
	mean ± SD	Min-max	mean ± SD	Min-max	mean ± SD	Min-max	mean ± SD	Min-max
Patients (n = 26)	**18.7;±;4.8**	11.3 to 28.3	**5.3** ± 2.5	1.1 to 11.3	**13.4;±;3.7**	8.0 to 21.5	**10.7** ± 4.7	2.2 to 22.7
Controls (n = 294)	**12.0;±;3.4**	3.2 to 22.3	**1.0** ± 2.5	−6.8 to 7.7	**11.0;±;3.1**	4.2 to 19.7	**1.9** ± 4.7	−11.9 to 14.1

Disaggregated results male/female								
Sex	Female	Male	Female	Male	Female	Male	Female	Male
	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
Patients (n = 26)	17.8 ± 3.7	19.5 ± 5.7	5.5 ± 2.3	5.0 ± 2.7	12.3 ± 2.9	14.5 ± 3.7	11.7 ± 4.8	9.8 ± 5.2
Controls (n = 294)	**11.6** ± 3.2	**12.4** ± 3.6	1.2 ± 2.5	0.8 ± 2.6	**10.4** ± 2.8	**11.7** ± 3.2	**2.4** ± 4.8	**1.4** ± 4.6

No. of patients above the respective cut-off				
Measurement	3D TT-TG	Only rot. TT-TG	Only trans. TT-TG	Both rot. aand trans. TT-TG
81% - cutoff	>15.0 mm	>3.2 mm	>13.7 mm	Rot>3.2 and trans>13.7 mm
Of patients (n = 26)	21 (81%)	11 (42%)	2 (8%)	8 (31%)

3D = three-dimensional; SD = standard deviation; TT-TG = tibial tuberosity to trochlear groove.

Table 2
TT-TG and tibiofemoral rotation are correlated; for each degree of rotation, TT-TG increases by about 0.5 mm. This table gives the details for this correlation in the patient and control cohort. Additionally, the interrater reliabilities given by their ICCs with their confidence intervals for the metrics used in this study are listed.

Correlation between tibiofemoral rotation and TT-TG				
Groups	Coefficient (95% CI)	p-value	RMSE	Adjusted r^2
Patients (n = 26)	0.49 (0.45–0.52)	**<0.001**	0.94	0.86
Controls (n = 294)	0.54 (0.53–0.54)	<0.001	0.28	0.99

Inter rater reliability		
Metric (n = 20)	ICC (A,1) (95% CI)	Evaluation
3D TT-TG	0.94 (0.90–0.97)	Good to excellent reliability
Translational TT-TG	0.82 (0.68–0.90)	Moderate to good reliability
Rotational TT-TG	0.92 (0.79–0.95)	Good to excellent reliability
Tibiofemoral rotation	0.99 (0.98–0.99)	Excellent reliability

3D = three-dimensional; CI = confidence interval; ICC = intraclass correlation coefficient; RMSE = root mean square error; SD = standard deviation; TT-TG = tibial tuberosity to trochlear groove.

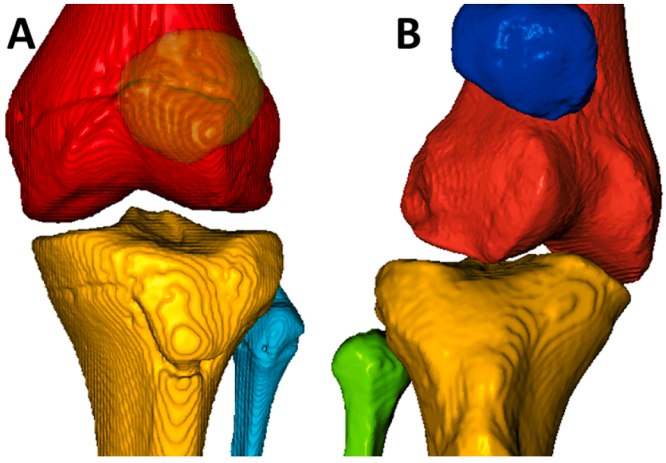

Fig. 4. (A) In some patients, high overall TT-TG (in Figure: 22.4 mm) is caused by high translational TT-TG (in Figure: 18.9 mm) and average rotational TT-TG (in Figure: 3.4 mm). (B) In other patients, however, high overall TT-TG (in Figure: 22.9 mm) can be caused by average translational TT-TG (in Figure: 11.6 mm) and high rotational TT-TG (in Figure: 11.3 mm). Even though both patient knees shown present with similar overall 3D TT-TG, the optimal treatment strategy to preserve their joints in the long term might be different. TT-TG = tibial tuberosity to trochlear groove.

substantial concern in the assessment and treatment planning for PFI patients.

First, our findings shed light on the determinants of elevated TT-TG, revealing differences in both tibiofemoral rotation (i.e. the rotational component of TT-TG) and mediolateral morphology (i.e. the translational component of TT-TG) acting as drivers of the elevated TT-TG values in PFI patients. That said, the greater difference between patient and control means for rotational vs. translational TT-TG (4.5 vs. 2.4 mm) indicates that tibiofemoral rotation is a stronger contributing factor for the overall difference in TT-TG between patients and controls.

Second, our study found no significant correlation between rotational and translational TT-TG, meaning that high TT-TG patients can present with high translational TT-TG (see Fig. 4A), high rotational TT-TG (see Fig. 4B), or both. Accordingly, we established cut-off values for elevated translational and rotational TT-TG and showed that patients with high TT-TG can be above one of those threshold values or both.

Third, given the strong correlation between rotational TT-TG and tibiofemoral rotation (r2 = 0.86), tibiofemoral rotation must be acknowledged as a substantial concern in the treatment of PFI patients [3,3,19,20]. Notably, the estimate resulting from our linear regression that 1 degree of tibiofemoral rotation causes approximately a 0.5 mm increase in rotational TT-TG can serve as a general guideline in understanding the relationship between tibiofemoral rotation and overall TT-TG, similar to previous results [21]. Therefore, surgeons could reasonably estimate rotational TT-TG purely by measuring tibiofemoral rotation on 2D imaging without the need for the 3D method to measure rotational TT-TG. In the control cohort, statistically higher tibiofemoral rotation was found in female participants. A similar nonstatistically significant difference in means was found between female and male patients. These results indicate that high external tibiofemoral rotation is more common in females.

As shown by the work by Pascual-Leone et al. [22] external tibiofemoral rotation varies from scan to scan and cannot be considered a fixed metric. Our research has shown that contrarily to the rotational component of TT-TG, the translational component is essentially independent from tibiofemoral rotation. Therefore, while high translational TT-TG could reliably indicate a need for intervention, high rotational TT-TG could be an artifact, and caution is warranted. Furthermore, the variability in tibiofemoral rotation leads to a need for stringent and replicable imaging protocols. Still, perfect replication is unlikely and physicians should be careful about relying purely on TT-TG [11] and its rotational component. Thus, physician should consider using other metrics in tandem [9].

These findings could have several implications for clinical decision-making because translational TT-TG is primarily dependent on the mediolateral positions of the trochlear groove and the tibial tuberosity, reducing it with a tibial tuberosity osteotomy seems relatively straightforward. Tibiofemoral rotation can potentially be addressed in moderate cases with more conservative methods, such as training hip and knee stabilizers (e.g. unilateral training like the Bulgarian split squat [23] or dedicated physical therapy programs [24]), or with invasive surgical approaches to directly decrease tibiofemoral rotation, such as a derotational osteotomy. However, selection of any of these treatment plans would require a more advanced understanding of the root cause of the tibiofemoral rotation in PFI itself, such as tibiofemoral morphology and active and passive soft tissue contributions. Alternatively, the surgeon has the option to compensate for increased rotational TT-TG with a reduction of the translational TT-TG, thus reducing overall 3D TT-TG.

Currently the morphological or translational component of joint alignment is primarily measured via the tibial tuberosity to posterior ligament attachment site distance (TT-PCL). The TT-PCL is established and easily assessed, but it does not consider the location of the trochlear groove. Additionally, it makes it difficult to assess how much the TT-TG distance is due to tibiofemoral rotation as TT-PCL uses different reference points compared to TT-TG. Therefore, physicians cannot readily use TT-PCL to estimate both the rotational and translational components of joint alignment.

Limitations

The patient scans were included retrospectively. Therefore, we were not able to control imaging protocols and patient placement, which might have impacted the tibiofemoral rotation of patients at the time of scanning [22]. However, since the variance of rotational TT-TG of the patient cohort was not significantly different from that of the control cohort, which was imaged with a strict protocol, we believe this potential source of error plays a minor role.

The control cohort included in this study had a higher prevalence of osteoarthritis (OA) than the general population. Since elevated TT-TG is a risk factor for OA [25], we believe use of these controls can be regarded as conservative. The patient and control cohorts were not age-matched. Thus, we assumed that bony morphology impacting translational TT-TG and tibiofemoral rotation does not change with age in fully ossified joints. Currently we are not aware of any study empirically confirming that TT-TG does not change significantly after the joint is fully developed, but this is generally assumed to be the case in the field. Similarly, it has not been confirmed that tibiofemoral rotation as measured in this study does not change with age, but a study [26] on the Japanese population utilized a different tibiofemoral angle and indicates that there are no age-related effects.

The independence of the rotational and translational component was established via correlation analysis without a dedicated power analysis. Therefore, there might be an undiscovered weak correlation, which would still show that the components are largely independent.

CONCLUSION

TT-TG can be split into (1) a translational component, primarily dependent on bony morphology, and (2) a rotational component caused by external tibiofemoral rotation, both of which can lead to an elevated TT-TG measurement independently from each other. The rotational component is the primary factor for differences observed between PFI patients and controls but might vary between consequential patient scans. Our findings emphasize the importance of personalized treatment strategies tailored to individual patient profiles in treating patellar instability and will aid in more accurately targeted selection of surgical methods addressing either or both translational or rotational components of TT-TG.

Authorship contributions

1A: Conception and design of the study: Johannes M. Sieberer, John P. Fulkerson.

1B: Acquisition of data: Johannes M. Sieberer, Nancy Park, Shelby T. Desroches, Kelsey Brennan, Albert Rancu, Brooke McGinley, Armita R. Manafzadeh, Neil A. Segal, David Felson.

1C: Analysis and interpretation of Data: Johannes M. Sieberer, Steven M. Tommasini, Daniel H. Wiznia, John P. Fulkerson.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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