Do Demographic or Anthropometric Factors Affect Lateralization of the Tibial Tubercle in a Diverse Population?
A Magnetic Resonance Imaging Analysis

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ABSTRACT

Introduction: The tibial tubercle-trochlear groove (TT-TG) distance is commonly used to evaluate and guide treatment for patellar instability. There is limited data available regarding TT-TG variability based on patient demographics and anthropometric factors.

Materials and Methods: TT-TG was measured on magnetic resonance imaging (MRI) for 384 consecutive adult patients. Demographic information for the corresponding was then gathered from the medical record and analyzed. Demographic variables analyzed included age, sex, race, height, weight, and body mass index (BMI).
Patello-femoral instability with subsequent subluxation and dislocation of the patella is a common orthopaedic problem with an incidence of approximately 2 to 3% of all knee injuries. Many risk factors for patello-femoral instability have been suggested including young age, female gender, history of prior dislocation, joint hypermobility, medial patello-femoral ligament (MPFL) disruption, vastus medialis obliquus weakness, patella alta, trochlea dysplasia, and increased tibial tubercle-trochlear groove distance (TT-TG). Increased TT-TG is thought to be one of the major risk factors for patello-femoral instability and anterior knee pain, and it is a widely used parameter for assessing and treating patello-femoral disorders. Goutallier et al. first described the TT-TG in 1978 as the medio-lateral distance between the tibial tubercle and the deepest part of the trochlear groove on an axial radiograph. The TT-TG measurement has since been refined and is typically calculated using axial computed tomography (CT) and/or magnetic resonance imaging (MRI) techniques. Multiple studies have demonstrated the pathological relevance of increased TT-TG as measured on MRI varies based on various patient demographics and anthropometric factors. The technique we used is similar to the one described by Wittstein et al. and Pandit et al. The midpoint of the distal insertion of the patellar tendon to the tibial tubercle was found.

Results: Mean TT-TG among the 384 patients was 12.68mm (standard deviation [SD]: 4.13mm, 95% confidence interval [CI] 12.26–13.10mm, range, 3.2–27.0mm), and there was a significant correlation with height (p=0.009), weight (p=0.017), and race (p<0.001). However, there was no significant correlation seen with sex (p=0.854), BMI (p=0.253), or age (p=0.096). Height and African American race were identified as independent predictors of increased TT-TG (p=0.007 and p<0.001, respectively); and females were found to have an increased TT-TG relative to height (p=0.015).

Conclusion: Tibial tubercle-trochlear groove distance was significantly correlated with race and height in the 384 patients examined. These findings may help explain clinical differences in these patients and help establish “norms” for patients of various ethnic and anthropometric variability.

INTRODUCTION

Patello-femoral instability with subsequent subluxation and dislocation of the patella is a common orthopaedic problem with an incidence of approximately 2 to 3% of all knee injuries. Many risk factors for patello-femoral instability have been suggested including young age, female gender, history of prior dislocation, joint hypermobility, medial patello-femoral ligament (MPFL) disruption, vastus medialis obliquus weakness, patella alta, trochlea dysplasia, and increased tibial tubercle-trochlear groove distance (TT-TG). Increased TT-TG is thought to be one of the major risk factors for patello-femoral instability and anterior knee pain, and it is a widely used parameter for assessing and treating patello-femoral disorders. Goutallier et al. first described the TT-TG in 1978 as the medio-lateral distance between the tibial tubercle and the deepest part of the trochlear groove on an axial radiograph. The TT-TG measurement has since been refined and is typically calculated using axial computed tomography (CT) and/or magnetic resonance imaging (MRI) techniques. Multiple studies have demonstrated the pathological relevance of increased TT-TG as measured on MRI varies based on various patient demographics and anthropometric factors. The technique we used is similar to the one described by Wittstein et al. and Pandit et al. The midpoint of the distal insertion of the patellar tendon to the tibial tubercle was found.

MATERIALS AND METHODS

Magnetic resonance imaging studies of the knee were retrospectively analyzed for 384 consecutive adult patients. The inclusion criteria were any patient aged 18 years or older who underwent an MRI of the knee at our institution during the period from June 1, 2009 to January 31, 2011. Patients who had gross patellar dislocation or evidence on imaging of recent patellar dislocation, or any altered normal anatomic relations from prior surgery, tumor, or fracture were excluded. The study was approved by our Institutional Review Board. Demographic patient data including age, gender, height, weight, body mass index (BMI), and race were recorded and used for comparative analyses.

All MRI images were obtained using the standard institutional knee MRI protocol using a 1.5 Tesla GE magnet. Fat-suppressed proton density axial sequences were reviewed, and measurements were performed using TraumaCad® orthopedic templating software (Brainlab, Inc., Feldkirchen, Germany).

The images were scrolled proximally until the first image depicting a complete cartilaginous trochlear groove was seen. At this level, a reference line was drawn tangent to the posterior condyles and a perpendicular line was brought up to the midpoint of the distal insertion of the patellar tendon to the tibial tubercle.
to the previously marked location of the midpoint of the patellar tendon insertion. The distance to the deepest point of the trochlear groove was measured parallel to the posterior condylar tangent (Fig. 1a–b).

Analyses of variance were used to compare TT-TG among different race groups, with Tukey’s test for post hoc analysis. Student t-tests were used to compare quantitative variables between two different groups and Pearson’s r tests were used to analyze the effect of quantitative variables such as age, height, weight, and BMI on TT-TG. A backward linear regression model was used to identify variables with independent statistical effects on TT-TG and to reveal any confounders.

**RESULTS**

In total, there were 253 females and 131 males. Mean patient age was 44 years (range, 18–83 years). Mean patient height and weight were 169.3 cm (range, 142.0–198.1 cm) and 87.2 kg (range, 47.4–151.1 kg), respectively. Patient mean BMI was 30.5 kg/m² (range, 16.1–53.8 kg/m²).

There were 206 patients who were African American, 76 Caucasian, 49 Hispanic, and 53 patients were identified as “Other”.

The mean TT-TG interval was 12.68 mm (standard deviation [SD]: 4.13 mm, 95% confidence interval [CI] 12.26–13.10 mm, range, 3.2–27.0 mm) among all subjects. Mean for females was 12.71 mm (SD: 4.09 mm, 95% CI 12.21–13.25 mm) and 12.65 mm for males (SD: 4.23 mm, 95% CI 11.91–13.37 mm). When analyzed by race, mean TT-TG in African Americans was 13.58 mm (SD: 4.29; 95% CI 13.00–14.20 mm), Caucasian was 12.24 mm (SD: 3.67; 95% CI 11.49–13.07 mm), Hispanic was 11.11 mm (SD: 3.49; 95% CI 10.12–12.04 mm), and “Other” was 11.28 mm (SD: 3.83; 95% CI 10.32–12.29 mm) (Fig. 2).

There was no significant effect of sex on TT-TG (p=0.854), but it was found to be significantly correlated with height (p=0.009, r=0.134) and weight (p=0.017, r=0.122) (Fig. 3). There was no statistically significant correlation between TT-TG and BMI (p=0.253) or age (p=0.096). Race did have a statistically significant effect on TT-TG (p=0.001 with ANOVA). Using Tukey’s
Figure 4. Average normal reported TT-TG in the literature. Reported standard deviation shown.

![Normal Values of TT-TG](image)

post hoc analysis, TT-TG in African Americans was found to be statistically different than in Hispanics (p=0.001) or “Other” (0.001). However, weight was also statistically higher in African Americans versus “Other” race groups (p<0.001). A backward linear regression model, taking into consideration race (as African American vs. non-African American), sex, height, and weight, showed that height and African American race were independent predictors of TT-TG (p=0.007 and p<0.001, respectively).

Mean TT-TG/height is 0.00709 in males and 0.00772 in females. The ratio of TT-TG to height was significantly larger in females versus males (p=0.015).

**DISCUSSION**

It is well-established that multiple factors predispose to patellar instability and anterior knee pain. Specific morphologic parameters include trochlear dysplasia, increased patellar height, lateral patellar tilt, and the lateralization of the tibial tuberosity relative to the trochlear groove. This study focused on understanding how the TT-TG distance varied based on patient characteristics such as age, sex, race, and anthropometric variables.

Our study found an overall mean TT-TG interval of 12.7 ± 3.67 mm. This value correlated with the findings of other authors, though there is much variability within the literature overall. Among asymptomatic patients, authors from different regions report mean TT-TG values ranging from 9.4 to 13.6 mm. The variability among the literature and the region of origin is demonstrated in Figure 4. Among symptomatic patients with patellar instability, mean TT-TG values range from 13.5 to 19.8 mm. Determining pathologic thresholds is also variable in the literature. Dejour et al. defined a TT-TG of greater than 20 mm as pathologic and an indication for a distal realignment procedure. The value of 20 mm was also used as the surgical threshold by Colvin et al. Koeter et al. considered a value >15 mm an indication for surgery if patient’s are symptomatic.

Of the above cited studies, some used CT and MRI and found a high correlation and determined that either modality could be used for reliable TT-TG assessment. Camp et al., on the other hand, found that MRI underestimated TT-TG by a mean of 2.3 mm in 59 knees with patellar instability. Nevertheless, an MRI scan does have advantages over CT scans as these studies allow for measurement of soft tissues, specifically the center of the patellar tendon as well as the cartilaginous portion of the trochlear groove. These provide for more anatomic measurements of TT-TG and better represent the direction of forces on the tendon when compared to bony landmarks. Additionally, MRIs pose no radiation risks to the patient and also allow evaluation of cartilaginous pathology.

Females have been reported to be affected by lateral patellar instability more frequently than males, with Stefanac et al. finding a male to female ratio of 46:54 among 1,763 first-time traumatic dislocations. Women who have already had a first-time patellar dislocation are three times more likely to have a subsequent dislocation than men. Yet, our study found no significant difference in TT-TG between genders (p=0.854), and this is consistent with the findings of other authors.

In our study, females were 13.5 cm shorter than males on average. Given our finding of a significant correlation between height and TT-TG, yet the lack of a difference in TT-TG between males and females, it stands to reason that females would have a higher TT-TG to height ratio than males. Our calculations confirmed this, showing a TT-TG to height ratio 8.9% higher in females than males (p=0.013). This may help to explain the higher dislocation rate in females.

Evaluation of patellar kinematics suggests that perhaps we should be evaluating the TT-TG distance relative to the size of the individual knee joint. Hingelbaum et al. used a “TT-TG index” where they calculated the ratio of TT-TG to the distance between the entrance of the trochlear groove proximally and the tibial tubercle distally. Using this method, the TT-TG was evaluated relative to the size of the knee joint and they did find a significant difference between males and females. Balcarek et al. evaluated the TT-TG distance relative to the width of the femur at the trans-epicondylar axis, but they did not find any significant impact on patellar instability.

In our study, we found a statistically significant correlation between TT-TG and height (p=0.010) and weight (p=0.012), but no correlation with BMI (p=0.187). These findings further support that TT-TG generally increases with patient “bone size”, but not with adiposity. TT-TG is an absolute value that does not take into account height, weight, or other anthropometric factors. Further investigation of a method to relate TT-TG to knee size may yield a more reliable predictor of patellar instability and anterior knee pain.

In 2014, the American Journal of Bone and Joint Surgery called for researchers to “consider potential sex and race differences when planning, performing, analyzing, and submitting their research” due to a paucity in the current
body of literature. In our diverse society, it is important to take into account sex and race as potential variables in musculoskeletal disease. We found race to have a statistically significant effect on TT-TG (p<0.001). TT-TG in African Americans (13.59 ± 4.30 mm) was found to be statistically different than Hispanics (11.04 ± 3.48 mm) (p=0.001) or “Other” (0.006). After controlling for other factors, increased height and African American race were found to be independent predictors of increased TT-TG (p=0.008 and p<0.001, respectively). To underscore the effect of race on TT-TG, a 2016 study by Kulkarni et al. evaluated normal knees in the Indian population. They concluded that their average normal TT-TG of 13.5 ± 3.11 mm is significantly higher than normal values reported in the Western population.

A study by Waterman et al., evaluating a database of patellar dislocations presenting to emergency departments over a six-year span, found that Caucasians and African Americans had over a four-fold greater incidence of patellar dislocation when compared with Hispanics. Hsiao et al. evaluated patellar dislocations among active duty United States military service members and found significantly higher incidences in African American and Caucasian service members as compared to the “Other” group which combined all other races. Anthropomorphic differences relating to the knee have been described as relating to race, but further clinical correlation could help guide treatment. Our study found higher than average TT-TG in the Caucasian and African American groups, and whether this difference explains the increased dislocation rate warrants further investigation.

A limitation of this study is that the indication for MRI was not recorded, and a history of patellar instability was not sought out in the patient history. Though no patients in our data set had any specific findings on MRI of gross patellar dislocation, evidence of recent patellar dislocation or any pathology that may artificially alter the normal anatomical relationships was not found. If we are to assume that rates of instability are relatively similar in all patient groups, then our conclusions regarding differences found among groups should hold valid even when patients are separated out based on symptoms. Another limitation of this study is that we do not have inter-observer and intra-observer reliability testing.

**CONCLUSION**

Various patient factors should be considered when evaluating TT-TG in the context of patellar instability or anterior knee pain. This study found that height and African American race are independent predictors of increased TT-TG. Also, females were shown to have an increased TT-TG relative to their height when compared to males. Previous studies have demonstrated that African Americans, Caucasians, and females have increased rates of patellar instability. Our study may help explain these findings.

**AUTHORS’ DISCLOSURES**

The authors have no conflicts of interest to disclose.

**REFERENCES**