



Anteroposterior distance between the tibial tuberosity and trochlear groove in patients with patellar instability

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ARTICLE INFO

Article history:

Received 22 March 2019

Received in revised form 3 July 2019

Accepted 25 August 2019

Keywords:

Patellar instability

Tibial tuberosity osteotomy

Trochlear groove

Trochlear dysplasia

ABSTRACT

Background: Our objective was to describe a measurement to assess sagittal tibial tuberosity (TT)–trochlear groove (TG) distance and to compare this between asymptomatic (control) patients and patients with symptomatic patellar instability.

Methods: We compared static CT images of 22 fully extended knees of patients with symptomatic patellar instability with images of 22 asymptomatic knees. TT–TG distance was measured to quantify lateralization of the TT, and anteroposterior TT–TG distance was used to quantify the sagittal distance between these two points. Lateral trochlear inclination, sulcus angle, and trochlear depth were measured. Groups were compared using paired *t* tests ($\alpha = 0.05$). Correlations of anteroposterior TT–TG distance with lateral trochlear inclination, sulcus angle, and trochlear depth were assessed using linear and multivariate regression.

Results: Mean TT–TG distances were 19.9 ± 4.4 mm (symptomatic) and 16.8 ± 5.5 mm (control) (mean \pm std deviation) ($P = 0.002$). Mean anteroposterior TT–TG distances were 8.3 ± 7.8 mm (symptomatic) and -0.5 ± 4.6 mm (control) ($P < 0.0001$). The symptomatic group had greater measurements of trochlear dysplasia, with lower lateral trochlear inclination, greater sulcus angle, and lower trochlear depth (all $P < 0.0001$). Anteroposterior TT–TG distance and trochlear depth were strongly negatively correlated ($r = 0.62$, $R^2 = 0.39$, $P < 0.0001$).

Conclusions: In asymptomatic patients, the anteroposterior TT–TG distance was -0.5 mm, indicating that the TG and TT were nearly in the same coronal plane. In patients with symptomatic patellar instability, the TG was almost nine millimeters anterior, and this distance correlated with measurements of trochlear dysplasia.

Level of evidence: III, case control study.

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1. Introduction

Extensor mechanism alignment is an important consideration in the treatment of patellofemoral pathology. In the coronal plane, lateralization of the tuberosity has been associated with increased incidence of instability, caused by lateralizing forces on the extensor mechanism.

Tibial tuberosity (TT) osteotomy is often performed for patients with patellar instability to correct this bony malalignment [1–5]. Determining whether a patient with patellar instability is an appropriate candidate for medializing TT osteotomy typically requires radiographic assessment of malalignment using TT–trochlear groove (TG) distance. Dejour et al. [6] showed that a TT–TG distance greater than 20 mm correlated with symptomatic patellar instability. Biomechanical studies [7,8] using imaging and computational modeling to characterize *in vivo* patellar tracking have shown that increased TT–TG distance is associated with increased lateralization and tilt of the patella [8], and that correction of TT–TG distance through TT osteotomy can improve patellar position [2]. Furthermore, recent biomechanical studies [9,10] reported that a TT–TG distance greater than 15 mm leads to increased strain on the medial patellofemoral ligament, emphasizing the importance of understanding the role of TT–TG distance when determining surgical treatment of patellar instability.

Although coronal plane malalignment is commonly assessed and addressed during the surgical treatment of patellar instability, the alignment in the sagittal plane is not often discussed.

Sagittal plane biomechanics of the patellofemoral joint often relate to chondral pathology, with anteriorization of tuberosity position, as described by Maquet [11], or anteromedialization, as described by Fulkerson [12], having been shown to reduce contact pressures within the patellofemoral joint [13]. Because of its ability to decrease patellofemoral contact pressures, anteromedializing TT osteotomy has been described for treating not only patellar instability but also patellar chondral lesions [14–17] and for use during patellofemoral cartilage restoration procedures [18–20]. With regard to the anteriorizing component of the TT osteotomy, an 8.8-mm anteriorization can decrease patellofemoral contact pressures by 30% in the lateral facet at 10° of knee flexion, and a 14.8-mm anteromedialization can reduce joint forces by 65% [4]. However, the ideal anteroposterior (AP) relationship of the TT to the TG in normal knees is unknown.

The aims of this study were to describe a measurement to assess the sagittal relationship between the TT and TG and to apply this in patients with symptomatic patellar instability and with age- and sex-matched asymptomatic (control) patients. Because trochlear dysplasia is common in patients with symptomatic patellar instability and can anteriorize the TG, our secondary aim was to describe the relationship between AP TT–TG distance and measurements of trochlear dysplasia. We hypothesized that a positive difference would exist between normal and symptomatic knees with relative anteriorization of the trochlear groove in symptomatic knees, and that a correlation would exist between AP TT–TG distance and measurements of trochlear dysplasia.

2. Methods

2.1. Study group

This study was approved by our institutional review board. Between 2015 and 2016, 18 patients (22 knees) underwent computed tomography (CT) as part of their preoperative workups at our institution. All knees were positioned in full extension during imaging, with the quadriceps relaxed. Patients were eligible for inclusion if they had symptoms of recurrent patellar instability that had not responded to nonoperative treatment and were aged 18 to 40 years. Patients with a history of osteotomy or bony surgical procedures on the symptomatic knee were excluded.

2.2. Control group

Asymptomatic knees of age- and sex-matched patients were identified through searching our institution's emergency department radiology database. These asymptomatic knees had been imaged as part of CT scanning of another body part, such as pan-scanning for trauma patients. Any patients with knee abnormality or history of knee surgery were excluded from the control group. A review of hospital records was performed to confirm that control patients had not received previous diagnoses or undergone procedures for the knee and that they did not report knee symptoms during their emergency department visits.

2.3. Knee flexion angle

Sagittal images were used to measure knee flexion angle at the time of imaging. The center slice through the intercondylar notch was selected, and lines through the axis of the femoral and tibial shafts were used to measure flexion angle. Knees that had been imaged in more than three degrees of flexion were excluded. Correlation between knee flexion angle and AP TT–TG distance was assessed to identify the role of positioning at the time of imaging on this measurement.

2.4. TT–TG and AP TT–TG distance

TT–TG distance was measured to quantify lateralization of the TT, which was represented as the distance between the most prominent point of the TT and the deepest portion of the TG on a line parallel to the posterior condylar axis (Figure 1A and

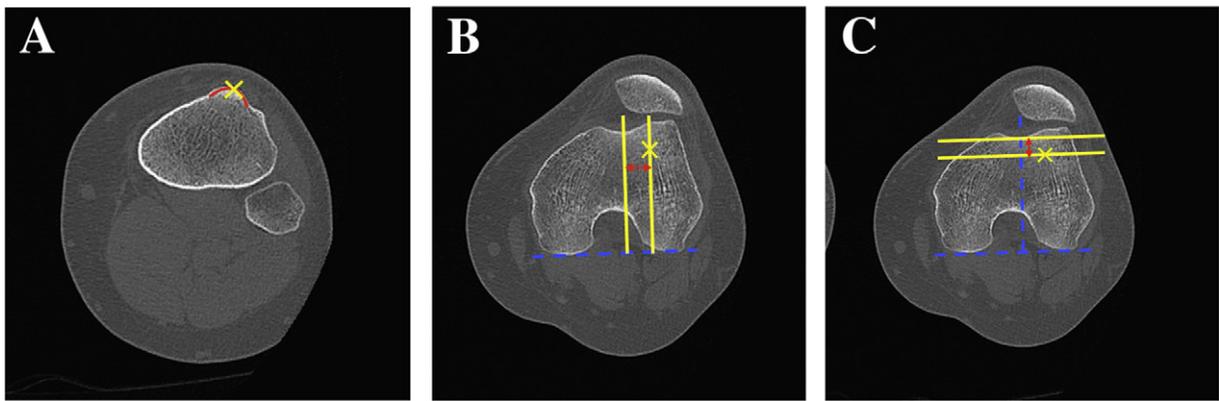


Figure 1. Computed tomography scans showing the (A) center of the tibial tuberosity (red arc) marked with a reference marker (yellow x), which remains consistent in all images. (B) The tibial tuberosity to trochlear groove distance (red line with arrows) was measured by finding the medial–lateral distance between the deepest portion of the trochlear groove and the reference marker (yellow lines), parallel to the posterior condylar axis (dotted blue line). (C) Anteroposterior distance between tibial tuberosity and trochlear groove (red line with arrows) was measured by finding the anteroposterior distance between the deepest portion of the trochlear groove and the reference marker (yellow lines), perpendicular to the posterior condylar axis (dotted blue line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

B). To do so without superimposing the images, we marked the center of the TT with a referencing marker (Figure 1A), which remained constant in all images. The medial–lateral distance to the TG was then measured parallel to the posterior condylar axis (Figure 1B). The axial slice showing the Roman arch of the posterior condyles was used to indicate the deepest portion of the TG. The AP distance between the TT and TG was defined as the AP distance between the most prominent point of the TT and the deepest portion of the TG, along a line perpendicular to the posterior condylar axis (Figure 1C). The reference point on the TT was used for this measurement (Figure 1A).

2.5. Measurements of trochlear dysplasia

Lateral trochlear inclination, sulcus angle, and trochlear depth were measured as indicators of trochlear dysplasia. Lateral trochlear inclination is the angle formed by a line from the deepest portion of the TG to the most prominent point on the lateral femoral condyle on axial imaging, with a line along the posterior condylar axis (Figure 2A) [21]. The sulcus angle is the angle formed between the deepest portion of the TG and the two most prominent points on the medial and lateral anterior condyles (Figure 2B) [22]. Trochlear depth was calculated, as described by Pfirrmann et al. [23], by subtracting the distance between the posterior condylar axis to the deepest point of the TG from the mean AP distance of the medial and lateral femoral condyles (Figure 2C). Trochlear depth of less than three millimeters is considered abnormal [23].

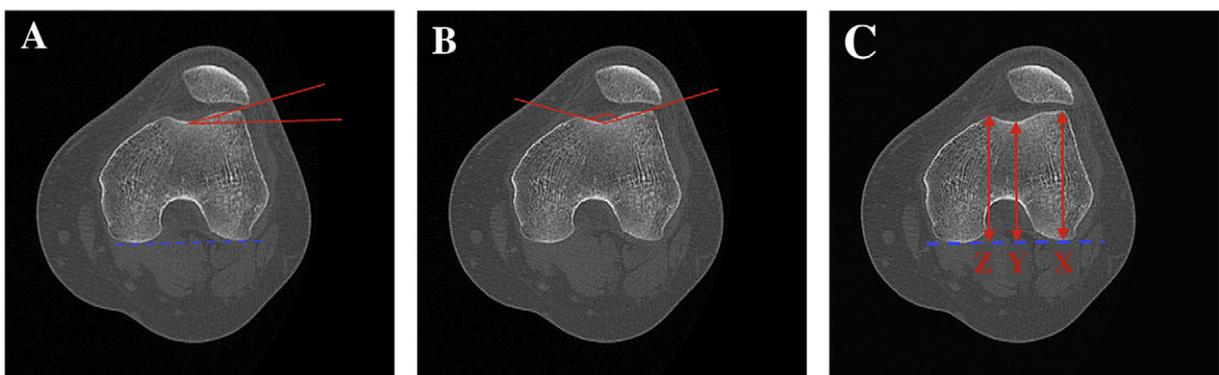


Figure 2. (A) Lateral trochlear inclination (red lines) was measured as the angle between a line from the deepest portion of the trochlear groove to the prominence of the lateral condyle and a line parallel to the posterior condylar axis (dotted blue line). (B) The sulcus angle was measured as the angle between the lines from the deepest portion of the trochlear groove to the most prominent points on the medial and lateral anterior condyles. (C) Trochlear depth $([X + Z / 2] - Y)$ was calculated by subtracting the distance from the posterior condylar line to the trochlear groove (Y) from the mean of the distances to the lateral femoral condyle and medial femoral condyle (X and Z) (B) from the mean of the distances to the lateral femoral condyle and medial femoral condyle (A and C). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.6. Measurement variability

Intra- and interobserver variabilities in the radiographic measurements were assessed [24]. Intraclass correlation coefficients for intraobserver variability were calculated from repeated measurements performed one week apart of 12 knees by one observer, a trained medical student who has performed measurements for prior studies. Coefficients for interobserver variability were calculated from repeated measurements of 12 knees, performed by three observers, including the medical student, a fellowship-trained sports medicine surgeon, and a musculoskeletal radiology researcher.

2.7. Statistical analysis

Measurements of TT–TG and AP TT–TG distance, lateral trochlear inclination, sulcus angle, and trochlear depth were compared between the symptomatic and control groups using paired t-tests. Correlations of AP TT–TG distance with TT–TG distance, lateral trochlear inclination, sulcus angle, and trochlear depth were assessed using linear regression. Multivariable regression was performed with AP TT–TG as the output and lateral trochlear inclination, sulcus, and trochlear depth as the input. A stepwise analysis was performed, and variables with P values >0.10 were excluded. Measurements were performed using CareStream software (Rochester, NY). $P < 0.05$ was considered statistically significant.

3. Results

3.1. Patients

The study group consisted of 22 knees from 18 patients (11 women) with symptomatic patellar instability; the mean patient age was 24 ± 5.2 years. The control group consisted of 22 knees from 19 patients (12 women); the mean patient age was 25.3 ± 5.2 years. Mean knee flexion angles were $-4.0^\circ \pm 4.0^\circ$ in the symptomatic group and $-1.4^\circ \pm 3.0^\circ$ in the control group (Table 1).

3.2. AP TT–TG distance

Normal AP TT–TG distance in the control group was -0.5 ± 4.6 mm, indicating that the trochlear floor was posterior to the TT in the sagittal plane. Mean AP TT–TG distance was 8.8 mm greater in the symptomatic group than the control group, indicating that the trochlea was more anterior to the TT in the symptomatic group ($P < 0.0001$). There was minimal correlation between knee flexion angle and AP TT–TG distance ($r = 0.13$, $R^2 = 0.02$, $P = 0.0038$).

3.3. TT–TG distance

Mean TT–TG distance was 3.1 mm greater in the symptomatic group than the control group ($P = 0.002$).

3.4. Correlation to measurements of trochlear dysplasia

The symptomatic group displayed greater trochlear dysplasia than the control group, with an 8.9° lower lateral trochlear inclination, 15° greater sulcus angle, and 4.7 mm smaller trochlear depth (all $P < 0.0001$). There were significant correlations between AP TT–TG distance and lateral trochlear inclination ($r = -0.51$, $R^2 = 0.23$, $P < 0.0001$) (Figure 3A) and between AP TT–TG distance and sulcus angle ($r = 0.31$, $R^2 = 0.10$, $P = 0.038$) (Figure 3B). A significant correlation also existed between AP TT–TG distance and trochlear depth ($r = -0.62$, $R^2 = 0.39$, $P < 0.0001$) (Figure 3C). Multivariate analysis showed that AP TT–TG distance is primarily negatively correlated with trochlear depth, with no significance in the other parameters, including TT–TG distance, when included with trochlear depth.

Table 1

Measures of TT–TG distance and trochlear dysplasia in patients with or without symptomatic patellar instability.

| Measures | Mean \pm SD | | Difference | P value |
|------------------------------------|----------------------|------------------|------------|---------|
| | Symptomatic (n = 22) | Control (n = 22) | | |
| TT–TG distance, mm | 19.9 \pm 4.4 | 16.8 \pm 5.5 | 3.1 | 0.002 |
| Anteroposterior TT–TG distance, mm | 8.3 \pm 7.8 | -0.5 \pm 4.6 | 8.8 | <0.0001 |
| Trochlear dysplasia indicators | | | | |
| Trochlear depth, mm | 1.3 \pm 2.9 | 6.0 \pm 2.5 | -4.7 | <0.0001 |
| Lateral trochlear inclination, | 13.0 \pm 7.3 | 21.9 \pm 3.5 | -8.9 | <0.0001 |
| Sulcus angle, | 153 \pm 10.5 | 138 \pm 7.1 | 15 | <0.0001 |
| Patella alta measurement | | | | |
| Caton–Deschamps index | 1.2 \pm 0.2 | 1.1 \pm 0.2 | 0.1 | 0.022 |

TT–TG, tibial tuberosity–trochlear groove.

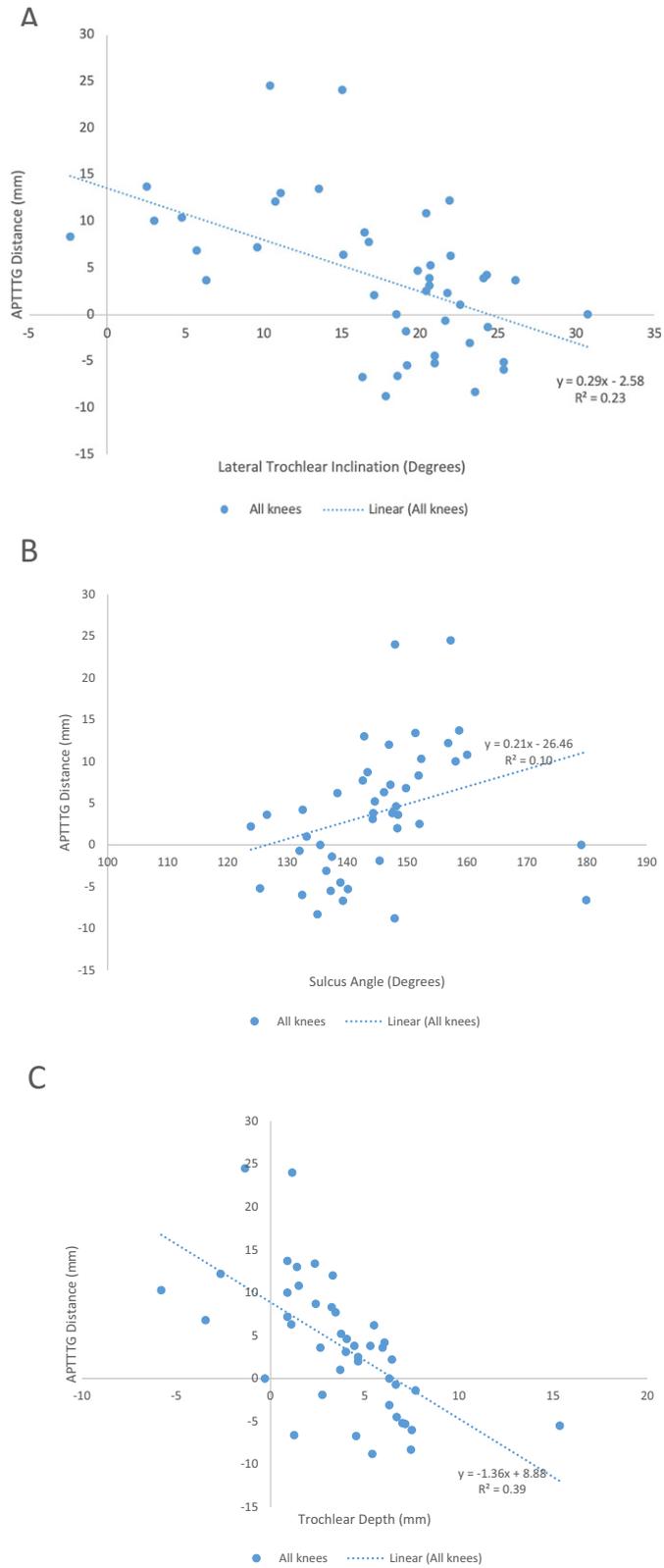


Figure 3. Linear regression model of symptomatic and control knees (n = 44) shows the relationships between (A) lateral trochlear inclination vs anteroposterior (AP) distance between the tibial tuberosity (TT) and trochlear groove (TG); (B) sulcus angle vs AP TT-TG distance; and (C) trochlear depth vs AP TT-TG distance.

3.5. Measurement variability

For TT–TG and AP TT–TG distances, measurement agreement among observers was excellent (>0.75). Interclass correlation coefficient for intraobserver variability was 0.966 [95% confidence interval 0.879, 0.991] for AP TT–TG distance. Interclass correlation coefficient for interobserver variability was 0.820 [95% confidence interval 0.589, 0.943] for AP TT–TG distance.

4. Discussion

Using CT imaging, we found that the AP distance between the TT and TG in control patients was -0.5 ± 4.6 mm, indicating that the TG was 0.5 mm posterior to the coronal plane of the tuberosity. The TG was almost nine millimeters more anterior to the TT in patients with symptomatic patellar instability than in asymptomatic patients, and this distance correlated with measurements of trochlear dysplasia, including a strong negative correlation with trochlear depth.

Sagittal plane kinematics in the patellofemoral joint have been studied in the context of anteriorization of the tuberosity and its effects on patellofemoral contact pressures. A cadaveric study [25] found that straight anteriorization osteotomy decreased total trochlear contact pressures without increasing medial patellofemoral pressures. The authors performed a 10-mm anteriorization without bone graft and measured contact pressures during simulated non-weight-bearing resisted knee extension. With loading of the extensor mechanism, the authors reported significant decreases in total contact pressures at 30° of knee extension (by 23% at 89 N and 20% at 178 N) and at 60° of knee extension (by 19% at 89 N and 32% at 178 N). Peak contact pressures also decreased significantly at 30° of knee flexion (by 24% at 89 N and 27% at 178 N), at 60° knee flexion (by 32% at 89 N and 24.5% at 178 N), and at 90° of knee flexion (by 13% at 81 N). The morphological characteristics of the trochlea in these knees were not reported. In a comparison of simulated medialization of the TT with anteromedialization in computational models of knees with symptomatic patellar instability, Elias et al. [26] reported that both procedures increased the medial patellofemoral contact pressures, with a smaller increase with anteromedialization than with medialization.

In these studies, the relative anteriorization of the tuberosity led to changes in the patellofemoral joint, yet the normal relationship between the two has not been described. Trochlear dysplasia has been described as an elevation of the trochlear floor, which could affect this sagittal relationship. However, patellofemoral contact pressures in the presence of trochlear dysplasia have not been commonly studied. The relative posteriorization of the TT in patients with trochlear dysplasia may suggest a relationship between trochlear dysplasia and elevated patellofemoral contact pressures [27]. Duran et al. [28] identified a relationship between trochlear morphology and chondral defects of the patella. They noted that chondral defects were more common in knees with greater trochlear dysplasia, as indicated by lower lateral trochlear inclination. They attributed this to increased lateral patellar displacement caused by trochlear morphology that could contribute to increased presence of chondral lesions. Although they did not perform other measurements of dysplasia such as trochlear depth, the association between trochlear dysplasia and chondral lesions suggests that further investigation into the relationship between trochlear dysplasia and patellar stability and patellofemoral contact pressures may be warranted.

Further examples of this include the historical Hauser procedure [29], which consisted of a distal and medializing TT osteotomy, resulting in posteriorization of the tuberosity. This was found to lead to increased degenerative changes with a high incidence of patellofemoral arthritis [30]. In terms of the existing relationship between the TT and TG in an individual, further study is needed to understand its role in patellofemoral contact pressures in the preoperative state because little is known about the developmental relationship between trochlear dysplasia and patellofemoral forces.

Trochlear dysplasia is a major factor in symptomatic patellar instability [6]. Multivariate analysis showed that trochlear dysplasia (diagnosed using the 2-scale Dejour classification) was the factor most strongly associated with recurrent dislocation, with an odds ratio of 3.6, indicating that trochlear dysplasia can increase the risk of the need for eventual surgical treatment. A dysplastic trochlea can have multiple morphologic elements, all of which lead to having a “shallow groove.” Contributors to this can be a hypoplastic medial or lateral condyle or an elevated floor of the TG [31,32]. Our findings of greater AP TT–TG distance and its relationship to trochlear depth suggest that the position of the trochlear floor, elevated in trochlear dysplasia, may contribute to increased AP TT–TG distance in symptomatic patients.

Jafaril et al. [33] performed computational modeling and reported the effects of TG geometry on the stability of the patellofemoral joint. They noted that an increased sulcus angle caused increased lateral shift and tilt of the patella, and that this effect was magnified when the medial retinaculum was released and total quadriceps force was increased. Similarly, computational models based on *in vivo* function have shown that lateral trochlear inclination correlates significantly with measurements of patellar lateralization and tilt at knee flexion angles of less than 20° in models of patients with recurrent patellar instability [7,34]. The trochleoplasty procedure has been introduced to address this. In particular, the Dejour trochleoplasty [35] and Bereiter trochleoplasty [36] are designed to deepen the TG and have been shown to improve stability and functional scores in European studies [37–42], although trochleoplasty is not yet a common procedure in the United States.

Alternatively, Chen et al. [43] reported on 25 knees with trochlear dysplasia and recurrent patellar instability that had good results after undergoing concurrent anteromedializing TT osteotomy during medial patellofemoral ligament reconstruction. Their patients (mean age, 21.5 years) included Dejour types B, C, and D. Seventeen of 25 patients had a TT–TG distance greater than 20 mm, and the remaining eight patients had a TT–TG distance of 13 to 20 mm. At a mean follow-up of 37 months, the authors reported improved Kujala and Lysholm scores, as well as decreased TT–TG distance and patellar tilt angle. They recommended this treatment for high-grade trochlear dysplasia and suggested that anteromedialization of the TT allowed correction

of the abnormal patellar motion created by the trochlear dysplasia, without using trochleoplasty. Further studies are needed to understand the role of sagittal alignment in the treatment of patellofemoral instability.

Limitations of this study include the fact that the control knees were identified retrospectively from CT scans of asymptomatic patients seen in the emergency department. Although the CT findings of control patients indicated a lack of abnormality and their records indicated no history of diagnoses or procedures on the knee, their lack of relevant knee history cannot be confirmed. Furthermore, CT imaging was performed using two different scanners in the control and study groups. Although each measurement was performed using the same software program, we are unable to account for potential differences in imaging between scanners. Additionally, although the patients in the study group underwent CT scanning with a consistent imaging protocol in full extension, this could not be confirmed for the control patients because of the nature of their conditions in the emergency department. Finally, the role of knee flexion angle was a consideration in the assessment of AP TT–TG distance, and regression analysis showed minimal correlation between the two. To eliminate the role of knee flexion angle, we excluded patients who had greater than three degrees of knee flexion on sagittal imaging from the control group and reported a slight difference of 2.6° greater knee flexion in the control group. Therefore, one could estimate that the actual AP TT–TG distance may be even lower (and the difference greater) than we report.

5. Conclusion

In control knees, the TG was 0.5 ± 4.6 mm posterior to the TT. In patients with patellar instability, the TG was almost nine millimeters more anterior to the TT compared with asymptomatic patients, and this distance correlated with measurements of trochlear dysplasia. Incorporating the measurement of sagittal alignment in patellofemoral pathology may have applications related to improving our assessment of patellofemoral contact pressures and stability. Furthermore, we supply a normal value of this measurement that provides a reference point for potential cases of reconstruction. Although further studies are needed to determine the relationship between AP TT–TG distance and patellofemoral pathology, our findings suggest that the AP relationship between the TG and TT may be a consideration in the assessment of sagittal alignment in patients with patellar instability.

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This study was approved by our institutional review board.

Declaration of competing interest

The authors declare no conflicts of interest. The authors did not receive any outside funding or grants in support of their research for or preparation of this work.

Acknowledgments

The authors thank Lynne C. Jones, PhD, for her assistance with the statistical analysis for this project.

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