

Effect of Medialization of the Trochlear Groove and Lateralization of the Tibial Tubercle on TT-TG Distance

A Cross-sectional Study of Dysplastic and Nondysplastic Knees

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Background: Tibial tubercle–trochlear groove (TT-TG) distance is often used as a measure of lateralization of the TT and is important for surgical planning.

Purpose: To investigate if increased TT-TG distance measured on axial magnetic resonance images is due to lateralization of the TT or medialization of the TG.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: A total of 84 knees (28 normal [NK], 28 with trochlear dysplasia [TD], and 28 with patellar dislocation without TD [PD]) were examined. The medial border of the posterior cruciate ligament (PCL) was chosen as the central anatomic landmark. The distance from the TT to PCL (TT-PCL) was measured to examine the lateralization of the TT. The distance from the TG to the PCL (TG-PCL) was measured to examine the medialization of the TG. Between-group differences were investigated by use of 1-way analysis of variance.

Results: The mean values for TT-TG distance were 8.7 ± 3.6 mm for NK, 12.1 ± 6.0 mm for PD, and 16.7 ± 4.3 mm in the TD group ($P < .01$). The mean values for TT-PCL distance were 18.5 ± 3.6 mm for NK, 18.5 ± 4.5 mm for PD, and 21.2 ± 4.2 mm in the TD group ($P = .03$). The mean values for TG-PCL distance were 9.6 ± 3.0 mm for NK, 7.1 ± 3.4 mm for PD, and 5.1 ± 3.3 mm in the dysplastic group ($P < .01$).

Conclusion: The present results indicate that increased TT-TG distance is due to medialization of the TG and not lateralization of the TT. Knees with TD had increased TT-TG distance compared with the knees of the control group and the knees with PD. The TT-PCL distance did not differ significantly between groups, whereas the TG-PCL distance declined with increased TT-TG.

Keywords: knee; patella; magnetic resonance imaging

Trochlea dysplasia (TD) is a developmental anatomic anomaly with a proximally flattened trochlear joint surface and a less pronounced concavity.¹⁸ This results in a weakened lateral osseous stabilizer to the patella and therefore an increased risk of lateral dislocation.³¹ Patella alta, increased tibial tubercle–trochlear groove (TT-TG) distance, and TD are all predisposing factors for patellar instability, among which TD is the most important risk factor.^{10,15,17,19}

In the literature, there is general agreement that measurement of the TT-TG distance is of particular importance in the assessment of patellar instability.²⁵ It is often recommended to treat increased TT-TG distance operatively by medializing the TT and thereby decreasing the TT-TG distance.¹³ However, an increased TT-TG distance is anatomically not a result of a single factor. It can be influenced by lateralization of the TT, medialization of the TG, or knee rotation.² Radiologically, an increased TT-TG distance can even be the result of the imaging modality and flexion angle during imaging.^{5,6} Therefore, it is important to evaluate which pathology an increased TT-TG distance reveals, as this can help us to better understand the underlying biomechanics of patellar instability and help to make correct surgical planning.

The purpose of the present study was to investigate if increased TT-TG distance measured by axial magnetic resonance imaging (MRI) is due to lateralization of the TT or medialization of the TG. To quantify the medialization of the TG, we have also introduced a new measurement called the trochlea groove–posterior cruciate ligament (TG-PCL) distance. We hypothesized that an increased TT-TG distance would be due to medialization of the TG rather than lateralization of the TT.

METHODS

This study was performed as a cross-sectional study of 3 groups of patients: a group of patients with TD who had at least 1 patellar dislocation (PD) and had experienced continued instability; a group of patients with patellar instability without TD; and a control group who experienced a tear of the anterior cruciate ligament (ACL) with no history or objective signs of patellar instability and without TD. The MRI data were collected from October 2010 to December 2017, and use of the data was approved by the required authorities. Patients with abnormal rotation as well as valgus formation above 5° were excluded. Screening for abnormal femoral torsion was performed with the patient in the prone position with the hips extended and the knees flexed to 90°, and a trochanteric prominence test was used. When in doubt, separate MRI scans including those of the hip, knee, and ankle were performed.

Participants

Patients chosen for the TD group were taken from a pool of patients with severe dysplasia who were treated with trochleoplasty by one of the authors (L.B.). All available patients treated during the past 5 years were included. The treating author used a combination of the following to select patients for trochleoplasty: decreased trochlear depth (<3 mm²⁷), and a flat or a convex trochlea and lateral trochlear inclination (LTI) <11°. The LTI was chosen over the Dejour classification as it quantifies the osseous stability of the patella and has proven its importance in the literature,²⁵ and the Dejour classification has shown poor reproducibility.^{4,20,23,24,28,32,35} Patients in the group with patellar instability without TD were identified through a search in the hospital's patient registry using the International Classification of Diseases, Tenth Revision (ICD-10) diagnosis code for PD (DS80.0). Patient journals were assessed to confirm that at least 1 PD had been present and that MRI results were available. Patients in the control group were identified through a search in the

hospital's patient registry using the ICD-10 diagnosis code for tears of the ACL (DS83.5). Patient journals were assessed to confirm that the patient had suffered from a tear of the ACL and had no history or objective signs of patellar instability.

The LTI was measured in the included knees to quantify the difference between the 3 groups. LTI was first presented by Carrillon et al.⁸ The measurement is performed by measuring the angle between a line adjacent to the posterior edges of the condyles and a tangential line to the subchondral lateral trochlear facet. The trochlear part of the measurement was performed on the most proximal image with a cartilage-coated trochlea, and this was related to a line parallel to both femoral condyles at the most well-defined point on the image.

Measurements

Three measurements were performed to evaluate the position of the TG: TT-TG distance, TT-PCL distance, and TG-PCL distance.

In this study, TT was measured as the insertion of the patellar ligament on the most proximal image where there was contact between the ligamentum patellae and the tibia. TG was measured as the deepest point in the groove on the most proximal image where a groove was observed at a minimum 2 mm with full cartilaginous coverage.

The slices adjacent to the slide being measured were scrolled through and averaged to create a 3-dimensional/2-dimensional compromise. The TT-TG distance was then measured as the lateral distance from the center of the tibial tuberosity to the TG, subtended perpendicular to the posterior femoral condylar line. Measurement of the TT-TG distance was found to be reliable with an intraclass correlation coefficient (ICC) of 0.99.³⁶

For the TT-PCL distance, the TT was measured the same way as previously mentioned. The PCL was measured on the most distal image where the medial boundary of the PCL could be identified. The TT-PCL distance was then measured as the lateral distance from the center of the tibial tuberosity to the medial boundary of the PCL, subtended perpendicular to the posterior tibial condylar line (Figure 1). This measurement was used as a quantitative expression for the lateralization of the TT. Measurement of the TT-PCL was found to be reliable with an ICC of 0.92.

For the TG-PCL distance, both the TG and the medial boundary of the PCL were measured as previously described. The TG-PCL distance was measured as the distance from the TG to the medial boundary of the PCL, subtended perpendicular to the posterior tibial condylar line.

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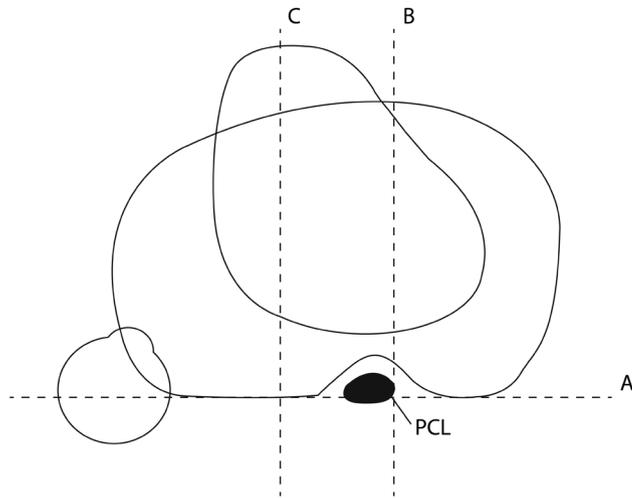


Figure 1. The TT-PCL distance runs from the medial boundary of the PCL to the center of the TT and as such is a measure of lateralization of the TT with regard to the PCL. A is a line tangential to the posterior tibial condylar line. B is the medial boundary of the PCL, subtended perpendicular to A. C is the center of the tibial tuberosity, subtended perpendicular to A. PCL, posterior cruciate ligament; TT, tibial tubercle.

This measurement was used as a quantitative expression for the medialization of the TG (Figure 2). The TG-PCL distance has not yet been reliability tested.

All measurements were performed by 2 experienced orthopaedic surgeons (L.B. and K.W.B.) and the average value was used. Both raters were blinded to which group the patient belonged to and the treatment/mode of surgery that was chosen. The ICC was calculated between the 2 raters. For the TT-TG distance, it was 0.95; for the TT-PCL distance, it was 0.65; for the TG-PCL distance, it was 0.65; and for the LTI, it was 0.92.

Statistical Analysis

The sample size was determined by the number of available patients with TD. A similar number of patients was found for the other 2 groups. Based on the exploratory type of the study and the unknown variability of the data, a power calculation was considered arbitrary and was not performed.

Statistical analysis was performed using Microsoft Excel 2019. The mean values and standard deviation were calculated for the TT-TG, TT-PCL, and TG-PCL distances. Between-group differences were investigated using 1-way analysis of variance.

RESULTS

A total of 84 knees were included, with 28 knees in each group (Table 1).

A statistically significant gradual increase in mean TT-TG distance was found between the 3 groups ($P < .01$): 8.7 ± 3.6 mm in the control group, 12.1 ± 6.0 mm in the

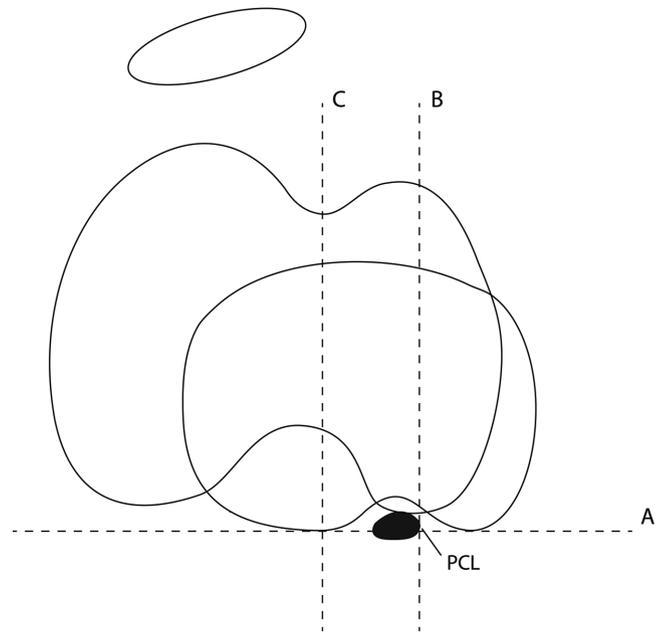


Figure 2. The TG-PCL distance runs from the medial boundary of the PCL to the center of the TG and as such is a measure of medialization of the TG with regard to the PCL. A is a line tangential to the posterior tibial condylar line. B is the medial boundary of the PCL, subtended perpendicular to A. C is the center of the TG, subtended perpendicular to A. PCL, posterior cruciate ligament; TG, trochlear groove.

TABLE 1
Overview of the Examined Groups^a

| | Sex (M/F) | Age, y | LTI, deg |
|---------------------------------|-----------|-------------|------------|
| Control group | 11/17 | 49.1 ± 19.6 | 18.2 ± 4.6 |
| Patellar dislocation without TD | 7/21 | 21.3 ± 8.2 | 15.6 ± 4.9 |
| Patellar dislocation with TD | 8/20 | 23.9 ± 9.0 | 4.7 ± 4.6 |

^aData are reported as mean ± SD unless otherwise indicated. F, female; LTI, lateral trochlear inclination; M, male; TD, trochlear dysplasia.

group with PD without TD, and 16.7 ± 4.3 mm in the group with TD (Table 2). The gradual increase in TT-TG distance was reflected in a likewise statistically significant decrease ($P < .01$) in TG-PCL distance, whereas the TT-PCL distance did not change between the groups ($P = .03$).

DISCUSSION

The most important finding of the study was that an increased TT-TG distance is due to medialization of the TG rather than lateralization of the TT.

Overall, the results indicate that knees with patellar instability and TD have an increased TT-TG distance compared with normal knees, and comparison with knees with

TABLE 2
Results of the mean values of the investigated groups. Between group differences were investigated using 1-way ANOVA

| | TT-TG, mm | TT-PCL, mm | TG-PCL, mm |
|--|------------|------------|------------|
| Control group | 8.7 ± 3.6 | 18.5 ± 3.6 | 9.6 ± 3.0 |
| Patellar dislocation without TD | 12.1 ± 6.0 | 18.5 ± 4.5 | 7.1 ± 3.4 |
| Patellar dislocation with TD | 16.7 ± 4.3 | 21.2 ± 4.2 | 5.1 ± 3.3 |
| Between-group difference (<i>P</i> value) | <.01 | .03 | <.01 |

^aData are reported as mean ± SD unless otherwise indicated. Between-group differences were investigated using 1-way analysis of variance (ANOVA). PCL, posterior cruciate ligament; TD, trochlear dysplasia; TG, trochlear groove; TT, tibial tubercle.

patellar instability without TD strengthens the already-established correlation between increased TT-TG distance and patellar instability.^{13,33}

The TG-PCL and the TT-PCL together constitute the TT-TG, except for the use of the posterior tibia as an interposed landmark between the points of interest on the femoral condyles. The TT-PCL distance is a pure measurement for lateralization of the TT with regard to the PCL,³ and the TG-PCL distance is therefore a measurement for the medialization of the TG.

The measured mean TT-PCL distance was the same in the control group, the group with PD without TD, and in the dysplastic group, which conflicts with existing knowledge stating that an increased TT-TG distance is a result of lateralization of the TT.^{1,3} The present results indicate that the TT was not lateralized in any of the groups with patellar instability compared with the control group (*P* = .03).

The measured mean TG-PCL distance was 9.6 mm in the control group and declined progressively to 7.1 mm in the group with PD without TD and 5.1 mm in the dysplastic group, indicating a progressive medialization of the TG with an increasing degree of patellar instability and dysplasia. The measurement of the TG-PCL distance is a new measurement that has not yet been presented in the literature or validated. The measure is an attempt to give an estimate of medialization of the TG. However, as the TG-PCL distance crosses the joint line, a rotational component can be present, and TG can be challenging to measure in knees with TD.

The present treatment of increased TT-TG distance and patellar instability is tibial tuberosity medialization. Thus, alignment of the TT and TG is achieved and the lateral working forces on the patella are reduced.^{21,26} The procedure was originally based on the assumption that the increased TT-TG distance was caused by lateralization of the TT.¹⁴ The present results question this assumption and indicate that trochleoplasty with lateralization of the TG would more likely to restore normal anatomy. It has been shown in the literature that trochleoplasty alone can significantly reduce the TT-TG distance.^{12,29}

If we aim to restore anatomy, it is worth considering doing a trochleoplasty instead of medializing the TT in

patients with borderline TD, who currently are often treated with medialization of the TT. However, patients without TD are treated successfully with medialization of the TT. It is a safe and well-established procedure with long-term follow-up that requires a moderate level of surgical skills.⁷ Trochleoplasty is still a less-established procedure, despite reviews^{16,22,38} demonstrating good and promising midterm follow-up. The procedure requires a high level of surgical skill but does not expose the patients to a higher degree of surgical comorbidity.³⁷

The present findings introduce a novel understanding of the TT-TG distance with regard to the trochlea, a finding that could influence anatomy and biomechanics of patellar instability and TD. Over time, the findings might help to develop better treatment options for the involved patients.

There are some limitations in this study that should be considered. It is a possible bias that the patients with TD were chosen from an operative list and the patients with PD and in the control group were randomly chosen based on ICD-10 codes. However, it would be very difficult to gather a group of patients with severe TD in another manner, and the LTI measurements show considerable differences between the 3 groups. In addition, when working with measurements, the reproducibility and variance always have to be taken into account. The TT-TG and TG-PCL distances have both been shown to have good reproducibility,^{9,30} although the TT-TG distance can be more challenging to measure on a dysplastic knee.^{11,34,36} Because the TG-PCL distance is a new measurement and has not yet been tested for reliability or validity, this limitation should be addressed in future studies. The landmarks used for the measurement are those used in the TT-TG and TG-PCL distances.

CONCLUSION

The present results indicate that an increased TT-TG distance is due to medialization of the TG and not lateralization of the TT. Knees with TD had an increased TT-TG distance compared with the knees of the control group and the knees with PD without TD. The TT-PCL distance did not differ significantly between groups, whereas the TG-PCL distance declined with increased TT-TG distance.

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