INSTRUCTIONAL REVIEW

Tibial tuberosity-trochlear groove distance: does it measure up?

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Recognized anatomic variations that lead to patella instability include patella alta and trochlear dysplasia. Lateralization of the extensor mechanism relative to the trochlea is often considered to be a contributing factor; however, controversy remains as to the degree this contributes to instability and how this should be measured. As the tibial tuberosity-trochlear groove (TT-TG) is one of most common imaging measurements to assess lateralization of the extensor mechanism, it is important to understand its strengths and weaknesses. Care needs to be taken while interpreting the TT-TG value as it is affected by many factors. Medializing tibial tubercle osteotomy is sometimes used to correct the TT-TG, but may not truly address the underlying anatomical problem. This review set out to determine whether the TT-TG distance sufficiently summarizes the pathoanatomy, and if this assists with planning of surgery in patellar instability.

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Introduction

Patellar instability is a common and potentially debilitating condition that predominately affects young people. It has an incidence of 5.8 per 100,000 people, which rises to 43 in 100,000 in adolescents, making it one of the most common knee presentations in adolescence.

The investigation and subsequent treatment of patellofemoral instability remains a challenge. Recognized risk factors include medial-patellofemoral ligament (MPFL) injury, torsional deformities, trochlear dysplasia, and patella alta. Lateralization of the force vector is considered important by many authors, but is less well understood.

A lateralized force vector may be due to a number of variations, which may be divided into bone or ligamentous factors, posture of the limb, muscle strength variations, and motor control. The relevant bony malalignments themselves can be further subdivided into torsional or coronal plane variations in the anatomy of the femur (either in the trochlea or elsewhere), or tibia (in the tubercle or the tibia more generally). A complex interplay between multiple anatomical factors have been identified in the many patients with recurrent patellar dislocations.

Tibial tuberosity-trochlear groove (TT-TG) distance is one of the commonest methods of assessing the lateral force vector contributing to patella instability. Steenson et al. reported on the prevalence of anatomical factors on MRI scans of 60 patients with patellofemoral instability compared to 120 controls. Patients with recurrent patellar dislocation possessed higher rates of patella alta (60.0% vs 20.8%), increased TT-TG distance (42.0% vs 3.2%), torsional deformity (26.7% vs 2.5%), and trochlear dysplasia (68.3% vs 5.8%) compared with patients without histories of patellar dislocation. This paper reiterates that underlying anatomy in patellar dislocation varies between individuals, but not that an elevated TT-TG should equate to a tibial tubercle osteotomy.

The TT-TG distance is a simple and easily assessed figure, with satisfactory inter- and intraobserver variability, but its robustness has been challenged. The TT-TG assesses the position of tibial tubercle in relation to trochlear groove, and not the absolute lateralization of the tibial tubercle. This may permit an understanding of functional lateral force and a dynamic assessment of patella tracking, but it may also mislead surgeons about the underlying cause of the problem.

History. The TT–TG was first described using radiograph; however, it is not without imaging errors, and a difference of up to 14 mm.
has been demonstrated between CT and radiograph measurement.\textsuperscript{9-12}
Dejour et al\textsuperscript{13} performed one of the landmark studies using CT and a fully extended knee to measure the TT-TG distance. They compared patients experiencing patellar instability and asymptomatic controls. On axial CT, the measurement was from a perpendicular line through the deepest point of trochlea, which should be drawn to the transverse line passing from the posterior end of the femoral condyles. Then, a parallel line was drawn to trochlea line starting from the centre of the most anterior part of the tibial tubercle (Figure 1).\textsuperscript{13} The mean TT-TG distance in the patellar instability group was 19.8 mm (standard deviation (SD) 1.6) compared with 12.7 mm (SD 3.4) in the control group (p < 0.01). They suggested a pathological threshold of 20 mm for this distance because 56% of the instability group patients had values greater than this, whereas only 3.5% of the control knees had values that high. Some surgeons have subsequently taken TT-TG distances greater than 20 mm to an indicator to offer a distal realignment procedure to reduce the risk of recurrent instability.\textsuperscript{4,12,13}

Reliability of measurement. Evidence shows good intra- and interobserver reliability for the measurement of TT-TG,\textsuperscript{10-12} with reported reliable intra- and interobserver coefficient of variation of less than 10%. The presence of dysplasia can pose challenge with one study demonstrating poor interobserver reliability of less than 60%.

Factors affecting TT-TG measurement. CT is able to produce high degrees of skeletal detail; however, MRI has advantages of avoidance of radiation exposure, and allows an assessment of the soft-tissue restraints and articular surface of the patellofemoral joint, and so reduces the need for multiple modes of imaging.\textsuperscript{14,15} Both CT and MRI have demonstrated a high degree of interobserver reliability.\textsuperscript{10,11,14-16}
Schoettle et al\textsuperscript{17} reported that TT-TG distances could be measured interchangeably using CT (mean 13.9 mm (SD 4.5)) or MRI (mean 14.4 mm (SD 5.4)). Subsequent studies have found that the MRI consistently gives between 3 to 4 mm lower values for TT-TG compared with CT (Table 1).\textsuperscript{18-20}
When using MRI, caution should be used when using the same TT-TG measurement values to guide surgical decision-making.

Landmarks. Soft-tissue definition with MRI has led surgeons to reconsider how they might select landmarks.\textsuperscript{16,18,20} Schoettle et al\textsuperscript{17} compared MR and CT images for measurement of lateral offset using traditional osseous landmarks and a more functional soft tissue landmark (the distance from the centre of the patellar tendon to the trochlear groove (PT-TG)). They concluded there was no difference between the measurements and hence they could be used interchangeably. Wilcox et al\textsuperscript{26} showed there was a difference of 4.18 mm between TT-TG and the PT-TG distances on MRI, as the patella tendon inserted relatively laterally compared to the bony tibial tubercle.

Trochlear groove. Trochlear groove measurement poses yet another challenge in terms of reliability and accuracy. Dejour et al\textsuperscript{13} defined this point a “which best represents the trochlea” which is open to interpretation. MRI has been used to identify a variety of cartilaginous landmarks at the point when the groove is the deepest.\textsuperscript{14-16,27,28} A frequently used landmark is ‘the most proximal slice on which a complete cartilaginous trochlea is seen’.\textsuperscript{27,28} In the dysplastic trochlear the lateral trochlear facet is considerably longer than the medial facet.\textsuperscript{21} The dominance of the lateral facet increases with the degree of Dejour’s classification of dysplasia.\textsuperscript{22} This leads to a medial migration of the groove and a ‘higher’ measurement of TT-TG.

The groove can be very difficult to measure in the presence of trochlea dysplasia, which to a greater or lesser degree is present in most of this population.\textsuperscript{7} Furthermore, a high value for TT-TG should not lead to osteotomy and medialization of the tubercle. Rather a considered evaluation for the presence of dysplasia should be made and addressed, with a deepening trochleoplasty to reduce the lateralised force vector.

Dynamic motion and limb alignment effect on TT-TG. TT-TG is a static measurement created when viewing two isolated images whether using radiograph, CT or MRI. Lateral patella dislocation is a dynamic event with the lateral vector force overcoming both soft-tissue and osseous constraints.

Quadriceps contraction and weightbearing. The use of dynamic imaging can help improve upon our understanding of the more functional component of patella

\textbf{Fig. 1} Illustration of tibial tuberosity-trochlear groove measurement.
...the tibial tubercle in extension. It is plausible that femur (screw home mechanism) leading to a lateralization of the tibia relative to the distal TG in full extension can be explained by the physiological TT-TG. MRI gives an 'apparent' lower value for TT-TG in weightbearing. Comparision of tibial tuberosity-trochlear groove (TT-TG) in varying flexion angles and weightbearing simulation.

| Author | Year | Knees imaged, n | Sex | Age, yrs, mean (SD) or median (IQR) | Recruitment | TT-TG by CT, mm (SD) | TT-TG by MRI, mm (SD) | Inter-rater reliability for TT-TG CT vs MRI, ICC | Inter-rater reliability for TT-TG CT vs MRI, difference (SD) |
|--------|------|-----------------|-----|-------------------------------------|-------------|---------------------|---------------------|-----------------------------------------------|-------------------------------------------------|
| Schottle21 | 2006 | 12 | 10.5 ± 2 M | N/A | Prospective | 14.4 (5.4) | 13.9 (4.5) | 0.82 | 0.5 (3.9) |
| Camp22 | 2013 | 59 | 31.3 ± 28 M | 24 (13 to 59) | Retrospective | 16.9 | 14.7 | N/A | N/A |
| Ho23 | 2015 | 59 | 31.8 ± 28 M | 32.8 (12.9) | Retrospective | 14.2 (4.5) | 11.7 (4.3) | 0.643 | 2.79 |
| Hinkel24 | 2015 | 50 | 34.5 ± 16 M | 28.7 (13.1) | Retrospective | 12.73 (4.25) | 9.3 (3.75) | N/A | 3.43 (3.87) |
| Anley25 | 2014 | 141 | 108 ± 33 M | 28.5 (11.13) | Retrospective | 17.72 (5.15) | 13.56 (6.07) | 0.54 to 0.48 | 4.16 |

Table II. Comparision of tibial tuberosity-trochlear groove (TT-TG) in varying flexion angles and weightbearing simulation.

Table I. Comparision of tibial tuberosity-trochlear groove (TT-TG) using MRI and CT scans.

It has been suggested that performing MRI in slight flexion may avoid the potential confounder of possible quadriceps activation and the screw home mechanism. However, the amount of flexion needs to be consistent and would interfere with an assessment of patella alta, which is considered by many surgeons to be a more important contributor to the pathology in patellar instability. Agreement about standardization of knee flexion in imaging for both patella alta and TT-TG, and research to collect normal reference ranges in that degree of flexion, is urgently needed.

**TT-TG variation in patient groups.** Dickens et al reported on TT-TG in asymptomatic subjects under the age of 16 years. Non-linear regression modelling showed that older children tended to have higher TT-TG distances, and that the values are most strongly associated with the natural logarithm of subject age (p < 0.001). The authors were able to develop a percentil-based growth chart (Figure 2).

While adolescents with patellar instability may have similar TT-TG values to adults, skeletally immature patients are best evaluated with a percentil-based growth chart when evaluating the relevance of TT-TG values.

**Sex and ethnicity.** Studies evaluating sex in relation to TT-TG measurements have not demonstrated significant differences. However there have been reported differences in TT-TG based on ethnicity. Mean TT-TG values in Caucasian, Chinese, Iranian, and Turkish populations have been reported between 10 to 12 mm. Mean TT-TG values have been reported to be significantly higher in an Indian population as 13.5 mm. Explanations for differences in TT-TG values between ethnicities have been suggested due to anthropological differences in osseous anatomy. Hernigou et al measured knee size and TT-TG using CT, and found...
improvement, but long-term data consistently shows it leads to long-term osteoarthritis (OA).\textsuperscript{48-50} Kujala scores.\textsuperscript{45} TTO medialization can lead to symptom in mean visual analogue scores for pain, and Lysholm and 15 mm showed excellent results significant improvement 60 patients treated with TTO corrected for a TT-\textsuperscript{TG} > 10 to between 10 and 15 mm. Koeter et al\textsuperscript{46} and Balcarek et a\textsuperscript{15,56} recommended 15 mm as a threshold for a medializing TTO, aiming to reduce the TT-\textsuperscript{TG} distance it relies only on tibial landmarks and is less affected by movement across the knee (i.e. tibial external rotation at terminal extension) or femoral anteversion. Further work is needed to establish what reasonable thresholds for treatment or correction might be, and the effect of those on the patellofemoral joint.

**Tibial tubercle-posterior cruciate ligament.** Seitlinger et al\textsuperscript{57} described a new technique of measuring tibial tuberosity-posterior cruciate ligament distance (TT-PCL) as the “mediolateral width between the tibial tubercle midpoint and the medial aspect of the PCL” (Figure 3), a reliable alternative for assessing lateralization of the tuberosity. They defined a TT-PCL distance < 24 mm as normal. One of the advantages of this measurement is that it relies on tibial landmarks and is less affected by movement across the knee (i.e. tibial external rotation at terminal extension) or femoral anteversion. Further work is needed to establish what reasonable thresholds for treatment or correction might be, and the effect of those on the patellofemoral joint.

**TT-TG index.** Hingelbaum et al\textsuperscript{58} designed a new knee size adjusted measure method to determine the TT-TG distance known as the TT-TG index. To determine joint size, the proximal-distal distance between the entrance of the chondral trochlear groove (TG) and the onset of the patella tendon at the T was selected. The index was calculated by dividing TT-TG/TT-TE. They suggested that a TT-TG index > 0.23 is pathological.

**PT-TG angle.** TT-TG and PT-TG measurements are limited in the fact that they only measure the translational component of the extensor mechanism deviations in the coronal plane, and do not completely represent the lateral quadriceps vector. There is strong association between
the PT-TG angles and distance with patellar tilt, and is more representative of the lateral quadriceps vector and does correlate well with patellar instability.\textsuperscript{59} 

**Patella instability ratios.** Camp et al\textsuperscript{60} studied 59 knees with patellar instability, the TT-TG distance, TT-PCL distance, sagittal patellar length (PL), sagittal trochlear length (TL), axial patellar width (PW), and axial trochlear width (TW). They found that a TT-TG distance > 20 mm was predictive of recurrent instability (odds ratio (OR) 5.38). The highest ORs for recurrent instability were noted for a TT-TG/ PW (OR 7.37) and a TT-TG/TW (OR 8.88). They conceptualized the TW as the “jump distance” that the patella must overcome for a dislocation to occur; this ratio accounts for patella trochlear engagement when assessing stability.

**MIELTI.** Tibial tuberosity mid inter-epicondyle trochlea intersection distance (TT-MIELTI) is a new method of identifying the deepest part of trochlea based on the femoral epicondyles.\textsuperscript{61} The measurement has shown excellent inter- and intraobserver reliability, with intraclass correlation coefficient (ICC) values of 0.86 and 0.89, respectively. The primary advantage of the TT-MIELTI is that it can be used irrespective of the degree of trochlear dysplasia, while still incorporating the contribution of the femoral component to the lateral offset.

In conclusion, TT-TG is one of the most common methods to assess the lateral force vector contributing to patellar instability. Many use this measurement to guide their surgical decision-making. In this literature review, we explore the strengths and weaknesses of the TT-TG as a measure to assess pathoanatomy, and as a guide for decision-making.

The use of MRI has been popularized and validated as an alternative to CT. The advantages of no radiation, and better tendon and chondral anatomy, have clear advantages. TT-TG values for MRI compared to CT are consistently lower and need to be redefined. One major consideration has to be the variability of knee position in the scanner at the time of scanning. As is demonstrated in the literature, increased knee flexion underestimates TT-TG distances. We recommend understanding that if a ‘knee coil’ has been used, documenting the position of knee flexion, trying to ensure control of hip and foot rotation, and keeping the knee orthogonal to the scanning gantry.

The current literature recommends that PT-TG has higher observer reliability for measurement, and furthermore, it is more of a functional landmark when assessing for a lateralized extensor mechanism. In the presence of trochlear dysplasia, a high TT-TG should not equate to a medializing osteotomy, and suitability of a deepening trochleoplasty should be assessed.

Patient population groups presenting with recurrent instability vary significantly. Variations in the child and adolescent populations need to be considered specifically. The use of growth charts can be very useful in this assessment. Ethnic variations emphasize the variations in knee size, height, and anthropological knee anatomy, which influence TT-TG distance measurements. Some of the alternative measurements seem to address some of the confounders in TT-TG measurement. Further studies are required to redefine MRI threshold values, and to validate the adjunct measures of TT-PCL, TT-TG index, TT-TG angles, patellar instability ratios, and TT-MIELTI.

Patellar instability can be caused by a multitude of factors, including MPFL injury, trochlear dysplasia, patella alta, and lateralization of the force vector. Each factor should be considered to have a variable contribution, and should be assessed as a potential contribution prior to considering surgery. TT-TG is one guide to help determine the need for a medializing TTO, although its interpretation is complex and the high rates of subsequent patellofemoral OA in patients treated this way imply that it should be used with caution.

In the past century, gross unmeasured medialization was a popular treatment for patellar instability that consistently and rapidly led to arthritis. In the opinion of the authors, surgery should aim to address the underlying anatomical pathology. Trochlear dysplasia, patella alta, and MPFL injury should be treated, if necessary, in combination. Correction of a lateralized tubercle should be reserved for those exceeding the upper end of the normal range.

**Take home message**

- Increased knee flexion underestimates tibial tuberosity-trochlear groove (TT-TG) distances.
- Patellar tendon to the trochlear groove has higher observer reliability for measurement.
- In the presence of trochlear dysplasia, a high TT-TG should not equate to a medializing osteotomy, and suitability of a deepening trochleoplasty should be assessed.
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