BJO

INSTRUCTIONAL REVIEW

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

H. Krishnan,
J. D. Eldridge,
D. Clark,
A. J. Metcalfe,
J. M. Stevens,
V. Mandalia

From Avon Orthopaedic Centre, Bristol, UK

Recognized anatomic variations that lead to patella instability include patella alta and trochlea 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.

Cite this article: *Bone Jt Open* **2022;3-3:268–274.**

Keywords: knee, stability, patella, TT-TG, osteotomy

Introduction

Patellar instability is a common and potentially debilitating condition that predominantly 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.[1]

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.[2-4]

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.[5,6]

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[7] 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 (TTO).

The TT-TG distance is a simple and easily assessed figure, with satisfactory intero- 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;[8] however, it is not without imaging errors, and a difference of up to 14 mm

Correspondence should be sent to Harry Krishnan; email: hk502@ic.ac.uk

doi: 10.1302/2633-1462.33.BJO-2021-0107

Bone Jt Open 2022;3-3:268–274.

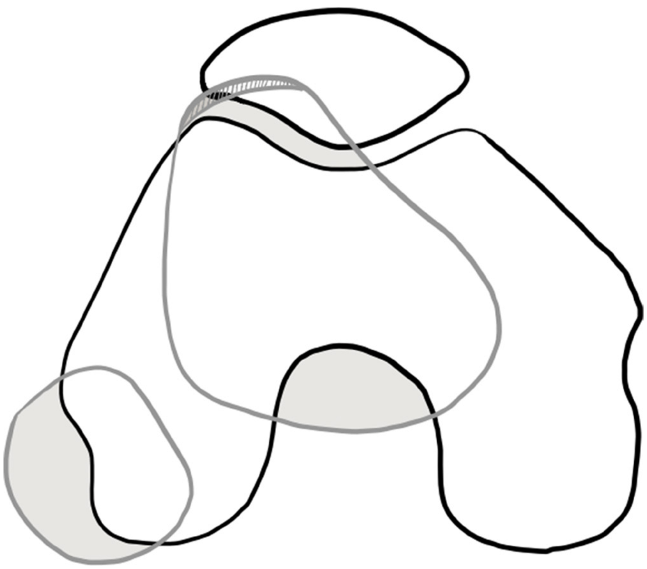

Fig. 1

Illustration of tibial tuberosity-trochlear groove measurement.

has been demonstrated between CT and radiograph measurement.[9-12]

Dejour et al[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).[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.[4,12,13]

Reliability of measurement. Evidence shows good intra- and interobserver reliability for the measurement of TT-TG,[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.[14,15] Both CT and MRI have demonstrated a high degree of interobserver reliability.[10,11,14–16]

Schoettle et al[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 I).[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.[16,18,20] Schoettle et al[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[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[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.[14–16,27,28] A frequently used landmark is 'the most proximal slice on which a complete cartilaginous trochlea is seen'.[27,28] In the dysplastic trochlear the lateral trochlear facet is considerably longer than the medial facet.[21] The dominance of the lateral facet increases with the degree of Dejour's classification of dysplasia.[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.[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

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

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)
Schottle[21]	2006	12	10 F, 2 M	N/A	Prospective	14.4 (5.4)	13.9 (4.5)	0.82	0.5 (3.9)
Camp[22]	2013	59	31 F, 28 M	24 (13 to 59)	Retrospective	16.9	14.7	0.53 to 0.54	2.23 (3.89)
Ho[23]	2015	59	31 F, 28 M	32.8 (12.9)	Retrospective	14.2 (4.5)	11.7 (4.3)	0.643	2.79
Hinckel[24]	2015	50	34 F, 16 M	28.7 (13.1)	Retrospective	12.73 (4.25)	9.3 (3.75)	N/A	3.43 (3.87)
Anley[25]	2015	141	108 F, 33 M	28.5 (11.13)	Retrospective	17.72 (5.15)	13.56 (6.07)	0.54 to 0.48	4.16

ICC, intraclass correlation coefficient; IQR, interquartile range; N/A, not applicable; SD, standard deviation.

Table II. 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)	Modality	NWB TT-TG 0°, mm (SD)	NWB TT-TG 15°, mm (SD)	NWB TT-TG 30°, mm (SD)	WB TT-TG 0°, mm (SD)	WB TT-TG 30°, mm (SD)
Izadpanah[29]	2013	8	7 F, 1 M	35 (7)	MRI	11.6 (4.4)	N/A	7.3 (2.9)	6.3.(3.2)	4.9 (3.9)
Hircshman[30]	2015	26	31 F, 28 M	57 (15.9)	CT	13.8 (5.1) to 13.9 (3.9)	N/A	N/A	10.5. (5) to 10.9. (5.2)	N/A
Dietrich[31]	2012	30	15 F,15 M	28.7 (5.3)	MRI	15.1 (3.2) to 14.8 (3.3)	10.0 (3.5) to 9.4 (3.0)	8.1 (3.4) to 8.6 (3.4)	N/A	N/A
Seitlinger[32]	2014	66	N/A	20.5 to 23.1	MRI	14 (6) to 10 (3)	13 (6) to 9 (4)	12 (6) to 10 (4)	N/A	N/A

N/A, not applicable; NWB, non-weightbearing; TT-TG, tibial tubercle-trochlear groove; WB, weightbearing..

instability. In clinical practice, it is not user-friendly and not a commonly used method for obtaining an MRI or CT scan.

Vastus medialis obliquus (VMO) muscle contraction is known to cause internal rotation of the tibia.[23] This leads to a reduction in TT-TG distance during quadriceps loading. With simulated weightbearing, measured TT-TG values have been shown to be 5 mm lower (Table II).[24] The change of the femora-tibial rotation from external rotation in non-weightbearing to internal rotation in weightbearing imaging may lead to a decrease of the TT-TG in weightbearing.[23,25]

Knee flexion. Knee position has a significant influence on TT-TG measurements. TT-TG has been reported to be between 5 mm and 7 mm higher in full extension compared to 30° flexion.[23,33,34] The significant increase in TT-TG in full extension can be explained by the physiological terminal external rotation of the tibia relative to the distal femur (screw home mechanism) leading to a lateralization of the tibial tubercle in extension.[22] It is plausible that the MR images are obtained in a knee coil in slight flexion and the CT images in full extension, which could help to explain why MRI gives an 'apparent' lower value for TT-TG.[31]

Measuring TT-TG with either modality assumes the long axis of the knee/lower limb and the scanner to be parallel. Measurements in the axial plane on either scanner are calibrated to be orthogonal to the scanner.[35] However, the positioning of the patient's knee relative to the scanner axis is imaging protocol dependent, and reproducibility and differences of patient positioning on the CT or MRI table have not been established.

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 my many surgeons to be a more important contributor to the pathology in patellar instability. Agreement about standardization of knee flexion angles 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[36] 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 percentile-based growth chart (Figure 2).

While adolescents with patellar instability may have similar TT-TG values to adults,[37,38] skeletally immature patients are best evaluated with a percentile-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.[14] 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.[14,16,39,40] Mean values have been reported to be significantly higher in an Indian population as 13.5 mm.[41]

Explanations for differences in TT-TG values between ethnicities have been suggested due to anthropological differences in osseous anatomy.[29] Hernigou et al[30] measured knee size and TT-TG using CT, and found

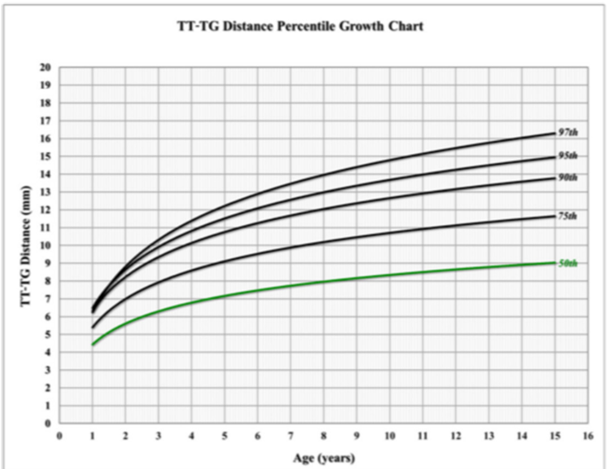

Fig. 2

Tibial tubercle-trochlear groove percentile growth chart.

proportional increase of TT-TG with the size of the knee in both stable and unstable patients. Their conclusion was to be cautious when interpreting cut-off values in smaller knees as a value of 14 mm maybe pathological in a smaller compared to a larger knee.

There are similarities of TT-TG measurements in Caucasian, Chinese, Turkish, and Middle Eastern populations; however, significant differences exist in Indian populations. Whether this is due to height or knee size differences was not ascertained.

Using TT-TG in surgical decision-making. Hauser[32] conceptualized the TTO in 1938, in which the tibial tubercle is moved distally and medially; unfortunately, osteoarthritic changes in the patellofemoral joint ensued. Various osteotomy techniques have since been described to 'correct abnormal' TT-TG values;[42–46] however, controversy exists at what the threshold values are.

Dejour et al[13] suggested the 20 mm as justification for a medializing TTO, aiming to reduce the TT-TG distance to between 10 and 15 mm. Koeter et al[46] and Balcarek et al[38] recommended 15 mm as a threshold for a medializing TTO.

Williams et al[47] used dynamic CT to assess TT-TG and patella, and suggested that patellofemoral tracking can be improved by reducing the TT-TG, but the study was very small and the long-term outcomes of these patients are not known. The ten-year follow-up results from 60 patients treated with TTO corrected for a TT-TG > 15 mm showed excellent results significant improvement in mean visual analogue scores for pain, and Lysholm and Kujala scores.[45] TTO medialization can lead to symptom improvement, but long-term data consistently shows it leads to long-term osteoarthritis (OA).[48-50]

The authors of this article do not recommend a specific technique. They recommend that any medialisation achieved during a TTO is to reduce excessive offset of the tibial tubercle relative to the trochlear groove rather than more extensive medialisation, which has documented high rates of patellofemoral arthritis.[49-52] This approach was clarified in a recent British Orthopaedic Association Standards for Trauma and Orthopaedics (BOASTs), which was developed following evidence review and consensus approach, with broad national consultation.[53] Because of the risk of late OA, the authors rarely use medializing tubercle osteotomy as a treatment for patellar instability, although it is sometimes used in cases with combined surgery, where a clear anatomical abnormality of tubercle position is apparent.

Sherman et al[54] reported that caution is needed when interpreting the tibial tuberosity-trochlear groove distance in the presence of excessive femoral anteversion and tibial external rotation. Greater tibial external rotation and excessive femoral anteversion have both been shown to elevated in patients with patellar instability.[55,56]

Patient selection remains the key as patellofemoral malalignment may not be identified with TT-TG alone, and the > 20 mm threshold may not be an appropriate indication for medialization of the tibial tubercle if used in isolation. Based on current literature, we cannot make specific recommendations as to the amount of medialization that should be achieved in a TTO based on current TT-TG measurements. The importance of torsional assessment using clinical and imaging methods should help guide TT-TG values, and may go some way in determining correction values.

Tibial tubercle-posterior cruciate ligament. Seitlinger et al[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 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.

TT-TG index. Hingelbaum et al[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

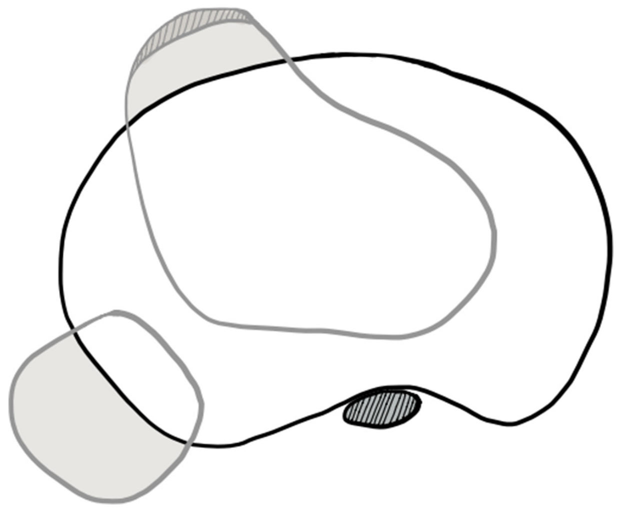

Fig. 3

Illustration of tibial tubercle-posterior cruciate ligament measurement.

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.[59]

Patella instability ratios. Camp et al[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.[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.

References

1. **Fithian DC**, **Paxton EW**, **Stone ML**, **et al**. Epidemiology and natural history of acute patellar dislocation. *Am J Sports Med*. 2004;32(5):1114–1121.
2. **Utting MR**, **Davies G**, **Newman JH**. Is anterior knee pain a predisposing factor to patellofemoral osteoarthritis? *Knee*. 2005;12(5):362–365.
3. **Conchie H**, **Clark D**, **Metcalfe A**, **Eldridge J**, **Whitehouse M**. Adolescent knee pain and patellar dislocations are associated with patellofemoral osteoarthritis in adulthood: a case control study. *Knee*. 2016;23(4):708–711.
4. **Dejour H**, **Walch G**, **Nove-Josserand L**, **Guier CH**. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc*. 1994;2(1):19–26.
5. **Desio SM**, **Burks RT**, **Bachus KN**. Soft tissue restraints to lateral patellar translation in the human knee. *Am J Sports Med*. 1998;26(1):59–65.
6. **Senavongse W**, **Amis AA**. The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability: a biomechanical study in vitro. *J Bone Joint Surg Br*. 2005;87-B(4):577–582.
7. **Steensen RN**, **Bentley JC**, **Trinh TQ**, **Backes JR**, **Wiltfong RE**. The prevalence and combined prevalences of anatomic factors associated with recurrent patellar dislocation: a magnetic resonance imaging study. *Am J Sports Med*. 2015;43(4):921–927.
8. **Goutallier D**, **Bernageau J**, **Lecudonnec B**. The measurement of the tibial tuberosity. Patella groove distanced technique and results (author's transl). *Rev Chir Orthop Reparatrice Appar Mot*. 1978;64(5):423–428.
9. **Wagenaar F. C**, **Koëter S**, **Anderson PG**, **Wymenga AB**. Conventional radiography cannot replace CT scanning in detecting tibial tubercle lateralisation. *Knee*. 2007;14(1):51–54.
10. **Smith TO**, **Davies L**, **Toms AP**, **Hing CB**, **Donell ST**. The reliability and validity of radiological assessment for patellar instability. A systematic review and meta-analysis. *Skeletal Radiol*. 2011;40(4):399–414.
11. **Saudan M**, **Fritschy D**. AT-TG (anterior tuberosity-trochlear groove): interobserver variability in CT measurements in subjects with patellar instability. *Rev Chir Orthop Reparatrice Appar Mot*. 2000;86(3):250–255.
12. **Lustig S**, **Servien E**, **Aït Si Selmi T**, **Neyret P**. Factors affecting reliability of TT-TG measurements before and after medialization: a CT-scan study. *Rev Chir Orthop Reparatrice Appar Mot*. 2006;92(5):429–436.
13. **Dejour D**, **Le Coultre B**. Osteotomies in patello-femoral instabilities. *Sports Med Arthrosc Rev*. 2018;26(1):8–15.
14. **Pandit S**, **Frampton C**, **Stoddart J**, **Lynskey T**. Magnetic resonance imaging assessment of tibial tuberosity-trochlear groove distance: normal values for males and females. *Int Orthop*. 2011;35(12):1799–1803.
15. **Wittstein JR**, **Bartlett EC**, **Easterbrook J**, **Byrd JC**. Magnetic resonance imaging evaluation of patellofemoral malalignment. *Arthrosc J Arthrosc Relat Surg*. 2006;22(6):643–649.
16. **Sobhanardekani M**, **Sobhan MR**, **Nafisi Moghadam R**, **Nabavinejad S**, **Razavi Ratki SK**. The normal value of tibial tubercle trochlear groove distance in patients with normal knee examinations using MRI. *Acta Med Iran*. 2017;55(9):573–577.
17. **Schoettle PB**, **Zanetti M**, **Seifert B**, **Pfirrmann CWA**, **Fucentese SF**, **Romero J**. The tibial tuberosity-trochlear groove distance; a comparative study between CT and MRI scanning. *Knee*. 2006;13(1):26–31.
18. **Camp CL**, **Stuart MJ**, **Krych AJ**, **et al**. CT and MRI measurements of tibial tubercle-trochlear groove distances are not equivalent in patients with patellar instability. *Am J Sports Med*. 2013;41(8):1835–1840.
19. **Ho CP**, **James EW**, **Surowiec RK**, **et al**. Systematic technique-dependent differences in CT versus MRI measurement of the tibial tubercle-trochlear groove distance. *Am J Sports Med*. 2015;43(3):675–682.
20. **Hinckel BB**, **Gobbi RG**, **Filho ENK**, **et al**. Are the osseous and tendinous-cartilaginous tibial tuberosity-trochlear groove distances the same on CT and MRI? *Skeletal Radiol*. 2015;44(8):1085–1093.
21. **Iranpour F**, **Merican AM**, **Dandachli W**, **Amis AA**, **Cobb JP**. The geometry of the trochlear groove. *Clin Orthop Relat Res*. 2010;468(3):782–788.
22. **Nelitz M**, **Lippacher S**, **Reichel H**, **Dornacher D**. Evaluation of trochlear dysplasia using MRI: correlation between the classification system of Dejour and objective parameters of trochlear dysplasia. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(1):120–127.
23. **Dietrich TJ**, **Betz M**, **Pfirrmann CWA**, **Koch PP**, **Fucentese SF**. End-stage extension of the knee and its influence on tibial tuberosity-trochlear groove distance (TTTG) in asymptomatic volunteers. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(1):214–218.
24. **Hirschmann A**, **Buck FM**, **Fucentese SF**, **Pfirrmann CWA**. Upright CT of the knee: the effect of weight-bearing on joint alignment. *Eur Radiol*. 2015;25(11):3398–3404.
25. **Wünschel M**, **Leichtle U**, **Obloh C**, **Wülker N**, **Müller O**. The effect of different quadriceps loading patterns on tibiofemoral joint kinematics and patellofemoral contact pressure during simulated partial weight-bearing knee flexion. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(7):1099–1106.
26. **Wilcox JJ**, **Snow BJ**, **Aoki SK**, **Hung M**, **Burks RT**. Does landmark selection affect the reliability of tibial tubercle-trochlear groove measurements uLandmark Selection Affect the Reliability of Tibial Tubercle-Trochlear Groove Measurements Using MRI? *Clin Orthop Relat Res*. 2012;470(8):2253–2260.
27. **Tscholl PM**, **Antoniadis A**, **Dietrich TJ**, **Koch PP**, **Fucentese SF**. The tibial-tubercle trochlear groove distance in patients with trochlear dysplasia: the influence of the proximally flat trochlea. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(9):2741–2747.
28. **van Huyssteen AL**, **Hendrix MRG**, **Barnett AJ**, **Wakeley CJ**, **Eldridge JDJ**. Cartilage-bone mismatch in the dysplastic trochlea. An MRI study. *J Bone Joint Surg Br*. 2006;88-B(5):688–691.
29. **Hingelbaum S**, **Best R**, **Huth J**, **Wagner D**, **Bauer G**, **Mauch F**. The TT-TG Index: a new knee size adjusted measure method to determine the TT-TG distance. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2388–2395.
30. **Hernigou J**, **Chahidi E**, **Bouaboula M**, **et al**. Knee size chart nomogram for evaluation of tibial tuberosity-trochlear groove distance in knees with or without history of patellofemoral instability. *Int Orthop*. 2018;42(12):2797–2806.
31. **Aarvold A**, **Pope A**, **Sakthivel VK**, **Ayer RV**. MRI performed on dedicated knee coils is inaccurate for the measurement of tibial tubercle trochlear groove distance. *Skeletal Radiol*. 2014;43(3):345–349.
32. **Hauser EDW**. Total tendon transplant for slipping patella: a new operation for recurrent dislocation of the patella. 1938. *Clin Orthop Relat Res*. 2006;452:7–16.
33. **Izadpanah K**, **Weitzel E**, **Vicari M**, **et al**. Influence of knee flexion angle and weight bearing on the Tibial Tuberosity-Trochlear Groove (TTTG) distance for evaluation of patellofemoral alignment. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(11):2655–2661.
34. **Seitlinger G**, **Scheurecker G**, **Högler R**, **Labey L**, **Innocenti B**, **Hofmann S**. The position of the tibia tubercle in 0°-90° flexion: comparing patients with patella dislocation to healthy volunteers. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2396–2400.
35. **Yao L**, **Gai N**, **Boutin RD**. Axial scan orientation and the tibial tubercle-trochlear groove distance: error analysis and correction. *AJR Am J Roentgenol*. 2014;202(6):1291–1296.
36. **Dickens AJ**, **Morrell NT**, **Doering A**, **Tandberg D**, **Treme G**. Tibial tubercle-trochlear groove distance: defining normal in a pediatric population. *J Bone Joint Surg Am*. 2014;96-A(4):318–324.
37. **Yeoh CSN**, **Lam KY**. Tibial tubercle to trochlear groove distance and index in children with one-time versus recurrent patellar dislocation: a magnetic resonance imaging study. *J Orthop Surg*. 2016;24(2):253–257.
38. **Balcarek P**, **Jung K**, **Frosch KH**, **Stürmer KM**. Value of the tibial tuberosity-trochlear groove distance in patellar instability in the young athlete. *Am J Sports Med*. 2011;39(8):1756–1761.
39. **Tse MSH**, **Lie CWH**, **Pan NY**, **Chan CH**, **Chow HL**, **Chan WL**. Tibial tuberosity-trochlear groove distance in Chinese patients with or without recurrent patellar dislocation. *J Orthop Surg*. 2015;23(2):180–181.
40. **Ortug A**, **Ormeci T**, **Yuzbasioglu N**, **Albay S**, **Seker M**. Evaluation of normal tibial tubercle to trochlear groove distance in adult Turkish population. *Niger J Clin Pract*. 2018;21(11):1403–1407.
41. **Kulkarni S**, **Shetty AP**, **Alva KK**, **Talekar S**, **Shetty VD**. Patellar instability in Indian population: relevance of tibial tuberosity and trochlear groove distance. *SICOT J*. 2016;2:14.
42. **MAQUET P**. A biomechanical treatment of femoro-patellar arthrosis: advancement of the patellar tendon. *Rev Rhum Mal Osteoartic*. 1963;30:779–783.
43. **Trillat A**. Diagnostic et traitement des subluxations recidevantes de la rotule. *Rev Chir Orthop*. 1964;50:813–824.
44. **Fulkerson JP**. Anteromedialization of the tibial tuberosity for patellofemoral malalignment. *Clin Orthop Relat Res*. 1983;177(NA;):176.
45. **Tigchelaar S**, **van Essen P**, **Bénard M**, **Koëter S**, **Wymenga A**. A self-centring osteotomy of the tibial tubercle for patellar maltracking or instability: results with ten-years' follow-up. *Bone Joint J*. 2015;97-B(3):329–336.
46. **Koëter S**, **Diks MJF**, **Anderson PG**, **Wymenga AB**. A modified tibial tubercle osteotomy for patellar maltracking: results at two years. *J Bone Joint Surg Br*. 2007;89(2):180–185.
47. **Williams AA**, **Elias JJ**, **Tanaka MJ**, **et al**. The relationship between tibial tuberosity–trochlear groove distance and abnormal patellar tracking in patients with unilateral patellar instability. *Arthrosc J Arthrosc Relat Surg*. 2016;32(1):55–61.

48. **Arnbjornsson A**, **Egund N**, **Rydling O**, **Stockerup R**, **Ryd L**. The natural history of recurrent dislocation of the patella. Long-term results of conservative and operative treatment. *J Bone Joint Surg Br*. 1992;74-B(1):140–142.
49. **Naveed MA**, **Ackroyd CE**, **Porteous AJ**. Long-term (ten- to 15-year) outcome of arthroscopically assisted Elmslie-Trillat tibial tubercle osteotomy. *Bone Joint J*. 2013;95-B(4):478–485.
50. **Nakagawa K**, **Wada Y**, **Minamide M**, **Tsuchiya A**, **Moriya H**. Deterioration of long-term clinical results after the Elmslie-Trillat procedure for dislocation of the patella. *J Bone Joint Surg Br*. 2002;84-B(6):861–864.
51. **Mani S**, **Kirkpatrick MS**, **Saranathan A**, **Smith LG**, **Cosgarea AJ**, **Elias JJ**. Tibial tuberosity osteotomy for patellofemoral realignment alters tibiofemoral kinematics. *Am J Sports Med*. 2011;39(5):1024–1031.
52. **Kuroda R**, **Kambic H**, **Valdevit A**, **Andrish JT**. Articular cartilage contact pressure after tibial tuberosity transfer. A cadaveric study. *Am J Sports Med*. 2001;29(4):403–409.
53. **British Orthopaedic Association**. Knee BOASTs: The surgical management of recurrent patellar instability. https://www.boa.ac.uk/standards-guidance/boasts/specialty-boasts.html (date last accessed 12 January 2022).
54. **Sherman SL**, **Erickson BJ**, **Cvetanovich GL**, **et al**. Tibial tuberosity osteotomy: indications, techniques, and outcomes. *Am J Sports Med*. 2014;42(8):2006–2017.
55. **Tensho K**, **Akaoka Y**, **Shimodaira H**, **et al**. What components comprise the measurement of the tibial tuberosity-trochlear groove distance in a patellar dislocation population? *J Bone Joint Surg Am*. 2015;97-A(17):1441–1448.
56. **Diederichs G**, **Köhlitz T**, **Kornaropoulos E**, **Heller MO**, **Vollnberg B**, **Scheffler S**. Magnetic resonance imaging analysis of rotational alignment in patients with patellar dislocations. *Am J Sports Med*. 2013;41(1):51–57.
57. **Seitlinger G**, **Scheurecker G**, **Högler R**, **Labey L**, **Innocenti B**, **Hofmann S**. Tibial tubercle-posterior cruciate ligament distance: a new measurement to define the position of the tibial tubercle in patients with patellar dislocation. *Am J Sports Med*. 2012;40(5):1119–1125.
58. **Hingelbaum S**, **Best R**, **Huth J**, **Wagner D**, **Bauer G**, **Mauch F**. The TT-TG Index: a new knee size adjusted measure method to determine the TT-TG distance. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2388–2395.
59. **Hinckel BB**, **Gobbi RG**, **Kihara Filho EN**, **Demange MK**, **Pécora JR**, **Camanho GL**. Patellar tendon-trochlear groove angle measurement: a new method for patellofemoral rotational analyses. *Orthop J Sports Med*. 2015;3(9):2325967115601031.
60. **Camp CL**, **Heidenreich MJ**, **Dahm DL**, **Stuart MJ**, **Levy BA**, **Krych AJ**. Individualizing the tibial tubercle-trochlear groove distance: Patellar instability ratios that predict recurrent instability. *Am J Sports Med*. 2016;44(2):393–399.
61. **Keehan R**, **Gill A**, **Smith L**, **Ahmad R**, **Eldridge J**. Mid inter-epicondyle trochlea intersection (MIELTI): Proposal of a new index for identifying the deepest part of the trochlea. *Knee*. 2019;26(6):1204–1209.

Author information:
- H. Krishnan, MBBS, BSc (Hons), MEd (ULT), FRCS(Tr&Orth), Consultant Orthopaedic Surgeon, Frimley Health Foundation Trust, Frimley, Surrey, United Kingdom.
- J. D. Eldridge, MBChB, BSc, FRCS, FRCS(Tr&Orth), Consultant Orthopaedic Surgeon
- D. Clark, MBBS, FRCS, MSc, MD, Consultant Orthopaedic Surgeon
  Avon Orthopaedic Centre, Southmead Hospital, Bristol, UK.
- A. J. Metcalfe, MBChB, FRCS, PHD, Consultant Orthopaedic Surgeon, Warwick Medical School, University of Warwick, University Hospitals of Coventry and Warwickshire, Coventry, UK.
- J. M. Stevens, MBBS, ChM, PGDip, FRACS, FAOrthA, Consultant Orthopaedic Surgeon, St Vincent's Hospital, Fitzroy, Melbourne, Australia.
- V. Mandalia, MBBS, FRCS(Tr&Orth), Princess Elizabeth Orthopaedic Centre, Royal Devon and Exeter Hospital, Exeter, UK.

Author contributions:
- H. Krishnan: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.
- J. D. Eldridge: Conceptualization, Writing – review & editing.
- D. Clark: Writing – review & editing.
- A. J. Metcalfe: Conceptualization, Writing – review & editing.
- J. M. Stevens: Writing – review & editing.
- V. Mandalia: Conceptualization, Writing – review & editing.

Funding statement:
- The author(s) received no financial or material support for the research, authorship, and/or publication of this article.

ICMJE COI statement:
- D. Clark reports payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events from Stryker; and a leadership or fiduciary role in a board, society, committee or advocacy group for Stadium Clinic, OSC, Rebus Medicolegal, and the British Patellofemoral Society, all of which are unrelated to this article. A. J. Metcalfe declares being the chief investigator for multiple NIHR funded studies and co-investigator for others. For three of these (START:REACTS, RACER-Knee, and RACER-Hip), Stryker pay for some of the treatment costs for people who participate. A. J. Metcalfe also reports being a member of a trial steering committee for three publicly-funded studies, and research lead for the British Association for Surgery of the Knee and the British Patellofemoral Society, all of which is also unrleated to this work.

Open access funding
- The authors report that the open access funding for this manuscript was self-funded.