Does Landmark Selection Affect the Reliability of Tibial Tubercle–Trochlear Groove Measurements Using MRI?

Jason J. Wilcox MD, Brian J. Snow MD,
Stephen K. Aoki MD, Man Hung PhD,
Robert T. Burks MD

Received: 29 August 2011 / Accepted: 19 January 2012 / Published online: 9 February 2012
© The Association of Bone and Joint Surgeons® 2012

Abstract

Background A lateralized tibial tubercle is one potential cause of patellar instability. The tibial tubercle–trochlear groove (TT-TG) distance using CT is a reliable measure and considered the gold standard. Using MRI for this purpose has increased, although the reliability of doing so is not well studied.

Questions/purposes We sought to (1) determine variability in the insertion of the patellar tendon relative to the tibial tubercle and whether this affects the measurement on MRI of

the traditional TT-TG distance versus the functional patellar tendon–trochlear groove (PT-TG) distance, (2) determine the reliability of measuring the osseous TT-TG distance, (3) determine the reliability of measuring the soft tissue PT-TG distance, and (4) compare the reliabilities of using osseous (TT-TG) versus soft tissue (PT-TG) landmarks.

Methods Four observers measured the TT-TG and the PT-TG distances of 50 MR images of knees obtained for any reason. Each observer repeated these measurements 30 days later. The interobserver and intraobserver reliabilities, measurements per observer that varied from the group mean by greater than 2 mm, and the limit of agreement were calculated.

Results The TT-TG and PT-TG differed by as little as 0.11 mm and by as much as 4.18 mm with an average difference of 1.37 mm. The interobserver and intraobserver reliabilities were greater than 90% for the PT-TG and TT-TG distances. The PT-TG distance was less variable in that this measurement showed interobserver and intraobserver reliabilities of 0.977 and 0.972 respectively, versus 0.913 and 0.961 for the TT-TG measurement. Additionally, the PT-TG measurements resulted in a lower average difference to the mean for each observer, less number of knees per observer where the difference to the mean was greater than 2 mm, and improved limit of agreement.

Conclusions The TT-TG and the PT-TG distances were not identical and differed by as much as 4.18 mm; as such they are not interchangeable when measuring this distance. Both methods are reliable for measuring lateral offset of the extensor mechanism, but the use of soft tissue landmarks is less variable and thus would provide a more reliable measurement for surgical planning.

Level of Evidence Level III, diagnostic study. See the Guidelines for Authors for a complete description of levels of evidence.

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request.

Clinical Orthopaedics and Related Research neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA-approval status, of any drug or device prior to clinical use. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained. This work was performed at the University of Utah Orthopaedic Center, Salt Lake City, UT, USA.

J. J. Wilcox (✉)
Department of Orthopaedics and Sports Medicine,
University of Washington, Seattle, WA, USA
e-mail: jwilcox2@u.washington.edu

B. J. Snow
Snow Orthopaedics, McKinney, TX, USA

S. K. Aoki, M. Hung, R. T. Burks
Department of Orthopaedics, University of Utah,
Salt Lake City, UT, USA

Introduction

Lateral patellofemoral instability is a potentially disabling condition, with an incidence of 5.8 per 100,000, and is even more common in a younger population [9, 11]. An increase in the TT-TG distance is one anatomic abnormality that may contribute to this condition [7, 29]. Procedures aimed at correcting the lateral offset of the extensor mechanism involve transferring the tibial tubercle medially or antero-medially [5, 10, 17, 18, 30].

The measurement of the TT-TG distance is most accurate and reliable when using imaging modalities [1, 21]. Among these, axial CT scan is the most extensively studied and considered the gold standard [6–8, 12–16, 19, 23, 26, 27, 29, 30]. However, MRI offers potential advantages over CT. MRI allows better observation of soft tissue injuries that may occur concomitantly with patellar instability, and the typically younger patient is not exposed to radiation to acquire the image.

Although measuring lateral offset of the extensor mechanism using MRI has been reported [2, 3, 14, 20, 30], the methods for doing so have not yet been validated [23, 26]. One deficiency is in defining which landmarks should be chosen to measure lateral offset. The tibial tubercle and the osseous trochlear groove are uniform landmarks in numerous studies using CT [7, 12, 13, 16, 29], but better observation of soft tissues has led to variability in landmark selection in studies using MR images [2, 3, 14, 20, 30]. One study [20] 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 center of the patellar tendon to the trochlear groove [PT-TG]), concluding that there was no difference and that they could be used interchangeably. The variability in the insertion of the patellar tendon relative to the anterior aspect of the tibial tubercle and the mismatch between the subchondral nadir of the femoral trochlea and its overlying cartilaginous nadir [22, 24, 25, 28] suggest the use of osseous and soft tissue landmarks might not be interchangeable when measuring the lateral offset of the extensor mechanism. An additional deficiency is defining the reliability of using MR images to measure this distance. Interobserver and intraobserver reliabilities and other measures of variability using CT images to measure the TT-TG distance have been defined [13, 20, 29]. Only one study has assessed interobserver reliability using MR images to measure the lateral offset (82%), but does not assess the intraobserver reliability of this measurement.

Given the variability in how this distance is measured using MRI, and the insufficient evidence [23] to support its use for this purpose, we sought to (1) determine variability in the insertion of the patellar tendon relative to the tibial tubercle and how this affects measurement of the traditional

TT-TG distance versus the functional PT-TG distance, (2) determine the reliability of measuring the osseous TT-TG distance, (3) determine the reliability of measuring the soft tissue PT-TG distance, and (4) compare the reliabilities of using osseous versus soft tissue landmarks.

Patients and Methods

We reviewed 55 consecutively obtained MR images of knees to obtain 50 quality studies taken at our institution for any indication between September 2009 and October 2009. We excluded five studies: three did not extend enough distally to adequately image the tibial tubercle, one did not adequately image the tibial tubercle and images were inadequate to perform measurements, and one used a poor technique precluding adequate measurements. A power analysis determined 50 patients using two observations would provide 80% power for intraobserver reliability ($F = 0.34$, $p = 0.05$) and that 50 patients using four observations would provide 80% power for interobserver reliability ($F = 0.16$, $p = 0.05$). Institutional Review Board approval was obtained before beginning the study.

The ages of patients included in this study ranged between 15 and 84 years. Twenty-one were females and 29 were males. Of the 50 studies included in this series, 22 were ordered owing to suspicion of a meniscal disorder, 11 for knee pain not otherwise specified, five for evaluation of ligament injury (three ACL, one PCL, one MCL), three for patellofemoral pain, three for popliteal cysts, two for evaluation of cartilage defects, two for soft tissue sarcomas, one for a suspected stress fracture, and one for evaluation of a peroneal nerve injury. All images were obtained on a Siemens MAGNETOM Avanto 1.5T scanner (Siemens Healthcare, Malvern, PA, USA). The axial sequence used was a fast spin echo proton density with fat suppression.

We performed measurements using Amira 5.2 software (Visage Imaging Inc, San Diego, CA, USA). This program allows linear and angular measurements to be made on axial images and maintained while scrolling through successive axial images. Measurements were performed in a similar manner as used in previous studies [7, 20, 30], and are described in detail below.

For osseous measurement, we selected the image with the best representation of the roman arch [7] (Fig. 1). A line connecting the most posterior aspect of the subchondral bone of each posterior femoral condyle was drawn. We then subtended a second line from the nadir of the osseous femoral trochlea perpendicular to the posterior condylar line. Both lines were maintained while scrolling inferiorly to the best image of the tibial tubercle. We then drew a third line from the most anterior aspect of the tibial tubercle perpendicular to the posterior condylar line. The

linear distance between the lines subtended from the tibial tubercle and the femoral trochlea were measured, which we recorded as the TT-TG in millimeters.

For soft tissue measurement, we drew the posterior condylar line on the image representing the best roman arch [7], connecting the most posterior aspects of the cartilage on the posterior femoral condyles (Fig. 2). A line subtended from the nadir of the cartilaginous femoral trochlea was drawn perpendicular to the posterior condylar line. These lines were maintained while scrolling to the image representing the most superior axial cut where the patellar tendon attaches to the tibia. We then subtended a line from the center of the patellar tendon, perpendicular to the posterior condylar line. We recorded the linear distance between the lines subtended from the patellar tendon and the femoral trochlea as the PT-TG distance in millimeters.

Each image series was devoid of patient identification and stored in numbered electronic folders. For all 50 knees, each of the four observers (JJW, BJS, SKA, RTB) made a total of four measurements. Each observer measured the TT-TG using osseous landmarks and the PT-TG distances using soft tissue landmarks, as described above. Each observer again measured the TT-TG and PT-TG distances after a minimum of 30 days to limit bias from previous measurements. The aggregate mean for the TT-TG and PT-TG distances, difference between these measurements, and standard deviations were calculated.

To determine the reproducibility, we calculated the interclass correlation coefficient and its 95% CI to determine interobserver and intraobserver reliabilities. To further measure rater variability, the mean of each observer's two measurements for TT-TG and again for PT-TG distances per knee were calculated, and the differences of

Fig. 1A–B Axial MR images show (A) a line subtended from the osseous nadir of the osseous femoral trochlea that is perpendicular to the posterior condylar line and (B) a line subtended from the most anterior aspect of the tibial tubercle that also is perpendicular to the posterior condylar line and parallel to the line subtended from the femoral trochlea. The distance between these parallel lines is the TT-TG distance.

Fig. 2A–B Axial MR images show (A) a line subtended from the cartilaginous nadir of the femoral trochlea that is perpendicular to the posterior condylar line and (B) a line subtended from the center of the patellar tendon that also is perpendicular to the posterior condylar line and parallel to the line subtended from the femoral trochlea. The distance between these parallel lines is the PT-TG distance.

these means from the mean TT-TG and PT-TG distances for all observers per knee also were calculated. We then used the Bland and Altman [4] method for determining the limit of agreement to determine how great a difference between two measurements must be before being able to detect a true difference that is greater than the measurement error.

Results

The center of the patellar tendon inserted lateral to the most anterior aspect of the tibial tubercle in 44 knees and medial to the most anterior aspect of the tibial tubercle in six knees. The average TT-TG distance measured 10.30 mm and the average PT-TG distance measured was 11.61 mm. The mean PT-TG distance was 1.37 mm more ($p = 0.04$) lateral than the mean TT-TG distance. The variability in measured offset between the osseous and soft tissue landmarks varied between 0.11 mm and 4.18 mm.

The interobserver reliabilities using osseous landmarks (TT-TG) were 0.918 and 0.911 for each set of measurements for a combined interobserver reliability of 0.913 (Table 1). The intraobserver reliabilities using the same landmarks were between 0.935 and 0.969, for a combined intraobserver reliability of 0.961 (Table 2). The average difference from the mean per observer varied between 0.26 and 1.81 mm when measuring the TT-TG distance (Table 3). The number of knees per observer where the measurement differed from the mean by 2 mm or greater occurred in as few as four knees for one observer and in 22 knees for another observer (Table 4). Using bony landmarks, there were 44 instances where an observer's reported measurement varied from the group mean by 2 mm or more. The limit of agreement varied between 2.8 mm and 3.3 mm per observer, and was 5.5 mm when calculated for all observers when measuring TT-TG (Table 5).

When making measurements using soft tissue landmarks (PT-TG), the intraclass correlation coefficient (ICC) for

interobserver reliabilities were 0.973 and 0.981 for a combined interobserver reliability of 0.977 (Table 1). The ICC calculated for intraobserver reliability measuring the PT-TG distance varied between 0.964 and 0.987. The ICC combining all observers using soft tissue landmarks was 0.972 (Table 2). The average difference to the mean for each observer varied between 0.06 mm and 0.20 mm (Table 3). For each observer measuring the PT-TG distance of 50 knees on two occasions each, there were only

Table 2. Intraobserver reliability of TT-TG and PT-TG measurements*

Observer	TT-TG	PT-TG
1	0.964 (95% CI, 0.936–0.979)	0.987 (95% CI, 0.977–0.992)
2	0.969 (95% CI, 0.945–0.982)	0.968 (95% CI, 0.934–0.984)
3	0.935 (95% CI, 0.867–0.966)	0.964 (95% CI, 0.937–0.980)
4	0.961 (95% CI, 0.931–0.978)	0.973 (95% CI, 0.953–0.985)
Total	0.961 (95% CI, 0.948–0.970)	0.972 (95% CI, 0.963–0.979)

* ICC with 95% CI; ICC = intraclass correlation coefficient; CI = confidence interval; TT-TG = tibial tubercle–trochlear groove; PT-TG = patellar tendon–trochlear groove.

Table 3. Mean difference for each observer

Observer	Mean (SD) difference from mean TT-TG (n = 50)	Mean (SD) difference from mean PT-TG (n = 50)
1	0.2634 (1.0999) mm	0.0686 (0.5860) mm
2	1.8082 (1.2881) mm	0.0645 (0.5841) mm
3	1.0381 (1.1672) mm	0.1998 (0.7065) mm
4	1.0335 (1.1892) mm	0.0665 (0.8752) mm

TT-TG = tibial tubercle–trochlear groove; PT-TG = patellar tendon–trochlear groove.

Table 4. Number of knees with difference to the mean greater than 2 mm

Observer	TT-TG (n = 50)	PT-TG (n = 50)
1	4	1
2	22	1
3	8	0
4	10	1

TT-TG = tibial tubercle–trochlear groove; PT-TG = patellar tendon–trochlear groove.

Table 1. Interobserver reliability of TT-TG and PT-TG measurements*

Measurement	TT-TG	PT-TG
1	0.918 (95% CI, 0.835–0.956)	0.973 (95% CI, 0.958–0.983)
2	0.911 (95% CI, 0.760–0.959)	0.981 (95% CI, 0.971–0.989)
Total	0.913 (95% CI, 0.811–0.953)	0.977 (95% CI, 0.968–0.983)

* ICC with 95% CI; ICC = intraclass correlation coefficient; CI = confidence interval; TT-TG = tibial tubercle–trochlear groove; PT-TG = patellar tendon–trochlear groove.

Table 5. Limits of reproducibility of TT-TG and PT-TG measurements*

Observer	TT-TG	PT-TG
1	2.8017 mm	2.1190 mm
2	2.7824 mm	2.6853 mm
3	3.2784 mm	2.6494 mm
4	2.8308 mm	2.5366 mm
Calculated 8 measurements	5.4511 mm	4.0773 mm

* Calculated on the basis of two measurements for each observer; TT-TG = tibial tubercle–trochlear groove; PT-TG = patellar tendon–trochlear groove.

three instances where an observer's mean differed from the mean by 2 mm or greater (Table 4). The limit of agreement varied between 2.1 mm and 2.7 mm for each observer, and was calculated to be 4.1 mm using all eight measurements per knee (Table 5).

When comparing the results of all measurements, the calculated interobserver reliability of 0.977 using the functional soft tissue landmarks was better ($p < 0.001$) than the interobserver reliability of 0.913 using the traditional osseous landmarks. Similarly, the calculated intraobserver reliability of 0.972 using soft tissue landmarks was better ($p = 0.009$) than that calculated when using osseous landmarks (0.961). When measuring the PT-TG distance, the three instances where the observers' measurements varied from the aggregate mean by greater than 2 mm was better ($p < 0.001$) than the 44 instances that occurred while measuring the traditional TT-TG distance on MR images. Additionally, the difference between two individual measurements using soft tissue landmarks needed to exceed 4.1 mm to be considered a real difference above measurement error and this difference was better ($p < 0.001$) than the 5.5 mm needed to detect a true difference when using osseous landmarks.

Discussion

An increase in the lateral offset of the tibial tubercle is one anatomic abnormality that may predispose a patient to have lateral patellar instability develop [7, 29]. Before proceeding with surgery to reduce the TT-TG distance [5, 10, 18, 30], some surgeons would prefer to know this distance is pathologic in relation to that of healthy control subjects. Measuring the TT-TG distance using CT images is well established and is considered the gold standard [13, 20, 23, 29]. Owing to better observation of soft tissues and the absence of radiation, the use of MRI to measure this distance is increasing [2, 3, 20, 21, 30], although the evidence for doing so is lacking [23]. Only one study [20] addresses

the interobserver reliability of using MRI to measure this distance, but does not address intraobserver reliability. Although the landmarks chosen to measure the TT-TG using CT are more uniform [1, 7, 8, 13, 20, 29], the studies using MRI to measure the lateral offset are far more variable in their choice of landmarks [2, 3, 20, 30], creating a source of variability. Given the small difference between what is considered a normal lateral offset and what is considered pathologic distance, the reliability of the measurement must be determined before using this measurement to plan a surgical procedure. Therefore, we sought to (1) determine variability in the insertion of the patellar tendon relative to the tibial tubercle and how this affects the measurement of the traditional TT-TG distance versus the more functional PT-TG distance, (2) determine the reliability of measuring the osseous TT-TG distance, (3) determine the reliability of measuring the soft tissue PT-TG distance, and (4) compare the reliabilities of using osseous versus soft tissue landmarks.

We acknowledge limitations to our study. First, we did not have CT images for any of these patients. Our ability to compare our results with those of the gold standard is limited to how our measured interobserver and intraobserver reliabilities and other calculated measures of variability compare with those published, rather than a direct comparison to a control group using CT images. Second, we used consecutive images that contained only three studies from patients with known patellofemoral symptoms. As our purpose was to determine the reliability of using each set of landmarks, our study population mimics that of the general population, and we cannot report the variabilities of abnormal TT-TG and PT-TG distances.

We found the patellar tendon inserted lateral to the most anterior aspect of the tibial tubercle in 44 of the 50 knees. Our mean osseous TT-TG was 10.3 mm and our mean soft tissue PT-TG distance was 11.61 mm. This relatively lateral insertion of the patellar tendon is consistent with the results of Schoettle et al. [20] using CT images (mean TT-TG of 14.4 mm, mean PT-TG of 15.3 mm), but not with their results using MR images (mean TT-TG of 13.9 mm, mean PT-TG of 13.5 mm). Our mean PT-TG of 1.37 mm was statistically more lateral than our mean TT-TG and although this figure is likely not clinically relevant, this difference was as much as 4.18 mm, which could be clinically important.

Our interobserver and intraobserver reliabilities were similar to those of other authors [13, 20, 29] measuring the TT-TG using radiographs, CT images, and MRI (Table 6). The number of knees per observer that varied from the mean by 2 mm or greater occurred 44 times in our series for all observers when measuring the TT-TG distance. Koeter et al. [13] reported this occurred 50 times using the double-image technique and 23 times when using the

single-image technique on CT images. They also reported a limit of agreement of 6 mm using the double-image technique and 4.5 mm using the single-image technique, suggesting that differences of 6 mm and 4.5 mm, respectively, would be required to detect a true difference between two measurements. Wagenaar et al. [29], using radiographs and CT images, reported limits of reproducibility of 18 mm and 4 mm, respectively. Our limit of agreement of 5.5 mm using MRI to measure the TT-TG compares with the results of these authors using CT images to make the same measurement.

Our interobserver and intraobserver reliabilities were similar to those reported using different imaging modalities (Table 6). The number of knees per observer that differed from the mean by 2 mm or greater occurred in only three instances in our series. No other study reports this in measuring the PT-TG, but our results compare favorably with the results of Koeter et al. [13], who reported

occurrences of 50 and 23 times in 50 knees using the double- and single-image techniques, respectively, when measuring the osseous TT-TG on CT images. Similarly, our limit of reproducibility was 4.5 mm which also compares with the 6 mm and 4.1 mm reported by Koeter et al. [13] using CT images, and 4 mm and 18 mm reported by Wagenaar et al. [29], using CT and radiographs, respectively, to measure the TT-TG distance.

Although using osseous (TT-TG) landmarks and soft tissue (PT-TG) landmarks appear to be reasonably reliable, the use of soft tissue landmarks was superior in improving interobserver reliability and intraobserver reliability. The average difference from the mean per observer was much better when measuring the PT-TG distance. The number of instances where an observer's measurement varied from the aggregate mean by 2 mm or more was reduced to three total instances from 44 when using soft tissue landmarks. The limit of agreement also was reduced to 4.1 mm on the

Table 6. Reported interobserver and intraobserver reliabilities of various measurements

Study	Modality	Landmarks	Interobserver reliability	Intraobserver reliability
Koeter et al. [13]	CT (2)	Tibial tubercle-osseous trochlea	0.98	0.913
Koeter et al. [13]	CT (1)	Tibial tubercle-osseous trochlea	0.97	0.972
Schoettle et al. [20]	CT	Tibial tubercle-osseous trochlea	0.82	Not reported
Schoettle et al. [20]	CT	Patellar tendon-cartilaginous trochlea	0.82	Not reported
Schoettle et al. [20]	MRI	Tibial tubercle-osseous trochlea	0.82	Not reported
Schoettle et al. [20]	MRI	Patellar tendon-cartilaginous trochlea	0.82	Not reported
Wagenaar et al. [29]	Radiograph	Tibial tubercle-osseous trochlea	0.948	0.862-0.891
Wagenaar et al. [29]	CT	Tibial tubercle-osseous trochlea	0.976	0.943-0.980
Current study	MRI	Tibial tubercle-osseous trochlea	0.913	0.961
Current study	MRI	Patellar tendon-cartilaginous trochlea	0.977	0.972

(1) = single image technique; (2) = double image technique.

Table 7. Reported TT-TG distances in symptomatic and asymptomatic patients

Study	Modality	Symptomatic TT-TG (mm)	Asymptomatic TT-TG (mm)	Landmarks
Alemparte et al. [1]	CT	Not reported	13.6	Tibial tubercle-osseous trochlea
Balcarek et al. [2]	MRI	12.75	10.66	Tibial tubercle-cartilaginous trochlea
Balcarek et al. [3]	MRI	12.6	11	Tibial tubercle-cartilaginous trochlea
Balcarek et al. [3]	MRI	14.1	10	Tibial tubercle-cartilaginous trochlea
Dejour et al. [7]	CT	19.8	12.7	Tibial tubercle-osseous trochlea
Schoettle et al. [20]	CT	14.4	Not reported	Tibial tubercle-osseous trochlea
Schoettle et al. [20]	CT	15.3	Not reported	Patellar tendon-cartilaginous trochlea
Schoettle et al. [20]	MRI	13.9	Not reported	Tibial tubercle-osseous trochlea
Schoettle et al. [20]	MRI	13.5	Not reported	Patellar tendon-cartilaginous trochlea
Wagenaar et al. [29]	Radiograph	14.86	Not reported	Tibial tubercle-osseous trochlea
Wagenaar et al. [29]	CT	17.04	Not reported	Tibial tubercle-osseous trochlea
Wittstein et al. [30]	MRI	12.6	9.4	Patellar tendon-deepest trough trochlea

TT-TG = tibial tubercle-trochlear groove.

PT-TG measurement, from 5.5 mm when measuring the TT-TG distance. Although no other study uses these latter three calculations to compare osseous versus soft tissue measurements, Koeter et al. [13] used them to determine the superiority of the now common single-image technique over the superimposed double-image technique. Our series would suggest a marked reduction in the variability of using soft tissue landmarks compared with osseous landmarks, but this finding is in direct contradiction to that of Schoettle et al. in the only other study [20] that addresses this issue.

The importance of our findings becomes evident when contrasting the measurements that are reported as normal TT-TG distances with those reported as pathologic distances in the existing literature (Table 7). Using CT images to measure the TT-TG distance, some authors [1, 7, 20, 29] report a pathologic threshold to be as low as 14.4 mm, whereas the average TT-TG distance in asymptomatic control subjects was as much as 12.7 mm. In studies using MRI [2, 3, 20, 30], the mean reported TT-TG distance in asymptomatic control subjects was as much as 11 mm, whereas the mean distance in symptomatic patients was as low as 12.6 mm. The small difference between normal and abnormal distances suggests the need to be uniform and reliable in how this distance is measured. Our data suggest that TT-TG and PT-TG distances are not the same, and although measuring the TT-TG and PT-TG distances is reliable, there is less variability when using soft tissue landmarks. Therefore, we believe the PT-TG distance should be used in lieu of the TT-TG distance when measuring lateral offset of the extensor mechanism of the knee on MR images.

References

1. Alemparte J, Ekdahl M, Burnier L, Hernandez R, Cardemil A, Cielo R, Danilla S. Patellofemoral evaluation with radiographs and computed tomography scans in 60 knees of asymptomatic subjects. *Arthroscopy*. 2007;23:170–177.
2. Balcarek P, Ammon J, Frosch S, Walde TA, Schuttrumpf JP, Ferlemann KG, Lill H, Sturmer KM, Frosch KH. Magnetic resonance imaging characteristics of the medial patellofemoral ligament lesion in acute lateral patellar dislocations considering trochlear dysplasia, patella alta, and tibial tuberosity-trochlear groove distance. *Arthroscopy*. 2010;26:926–935.
3. Balcarek P, Jung K, Ammon J, Walde TA, Frosch S, Schuttrumpf JP, Sturmer KM, Frosch KH. Anatomy of lateral patellar instability: trochlear dysplasia and tibial tubercle-trochlear groove distance is more pronounced in women who dislocate the patella. *Am J Sports Med*. 2010;38:2320–2327.
4. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307–310.
5. Cox JS. Evaluation of the Roux-Elmslie-Trillat procedure for knee extensor realignment. *Am J Sports Med*. 1982;10:303–310.
6. Davies AP, Costa ML, Shepstone L, Glasgow MM, Donell S. The sulcus angle and malalignment of the extensor mechanism of the knee. *J Bone Joint Surg Br*. 2000;82:1162–1166.
7. Dejour H, Walch G, Nove-Josserand L, Guier C. Factors of patellar instability: an anatomic radiographic study. *Knee Surg Sports Traumatol Arthrosc*. 1994;2:19–26.
8. Diks MJ, Wymenga AB, Anderson PG. Patients with lateral tracking patella have better pain relief following CT-guided tuberosity transfer than patients with unstable patella. *Knee Surg Sports Traumatol Arthrosc*. 2003;11:384–388.
9. Fithian DC, Paxton EW, Stone ML, Silva P, Davis DK, Elias DA, White LM. Epidemiology and natural history of acute patellar dislocation. *Am J Sports Med*. 2004;32:1114–1121.
10. Fulkerson JP. Anteromedialization of the tibial tuberosity for patellofemoral malalignment. *Clin Orthop Relat Res*. 1983;177:176–181.
11. Hawkins RJ, Bell RH, Anisette G. Acute patellar dislocations: the natural history. *Am J Sports Med*. 1986;14:117–120.
12. Koeter S, Diks MJ, Anderson PG, Wymenga AB. A modified tibial tubercle osteotomy for patellar maltracking: results at two years. *J Bone Joint Surg Br*. 2007;89:180–185.
13. Koeter S, Hortsman WG, Wagenaar FC, Huysse W, Wymenga AB, Anderson PG. A new CT scan method for measuring the tibial tubercle trochlear groove distance in patellar instability. *Knee*. 2007;14:128–132.
14. Koskinen SK, Taimela S, Nelimarkka O, Komu M, Jujala UM. Magnetic resonance imaging of patellofemoral relationships. *Skeletal Radiol*. 1993; 22:403–410.
15. Kujala UM, Osterman K, Korman M, Nelimarkka O, Hurme M, Taimela S. Patellofemoral relationships in recurrent patellar dislocation. *J Bone Joint Surg Br*. 1989;71:788–792.
16. Lustig S, Servien E, Ait Si Selmi T, Neyret P. [Factors affecting the reliability of TT-TG measurements before and after medialization: a CT scan study] [in French]. *Rev Chir Orthop Reparatrice Appar Mot*. 2006;92:429–436.
17. Maquet P. Advancement of the tibial tuberosity. *Clin Orthop Relat Res*. 1976;115:225–230.
18. Post WR, Fulkerson JP. Distal realignment of the patellofemoral joint: indications, effects, results, and recommendations. *Orthop Clin North Am*. 1992;23:631–643.
19. Saudan M, Fritschy D. [AT-TG (anterior tuberosity-trochlear groove): interobserver variability in CT measurements in subjects with patellar instability] [in French]. *Rev Chir Orthop Reparatrice Appar Mot*. 2000;86:250–255.
20. Schoettle PB, Zanetti M, Seifert B, Pfirrmann CW, Fucentese SF, Romero J. The tibial tuberosity-trochlear groove distance: a comparative study between CT and MRI scanning. *Knee*. 2006;13:26–31.
21. Shakespeare D, Fick D. Patellar instability: can the TT-TG distance be measured clinically? *Knee*. 2005;12:201–204.
22. Shih YE, Bull AM, Amis AA. The cartilaginous and osseous geometry of femoral trochlear groove. *Knee Surg Sports Traumatol Arthrosc*. 2004;12:300–306.
23. 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;40:399–414.
24. Staubli HU, Bosshard C, Porcellini P, Rauschnig W. Magnetic resonance imaging for articular cartilage: cartilage-bone mismatch. *Clin Sports Med*. 2002;21:417–433, viii–ix.
25. Staubli HU, Durrenmatt U, Porcellini P, Rauschnig W. Anatomy and surface geometry of the patellofemoral joint in the axial plane. *J Bone Joint Surg Br*. 1999;81:452–458.
26. Toms AP, Cahir J, Swift L, Donell ST. Imaging the femoral sulcus with ultrasound, CT, and MRI: reliability and generalizability in patients with patellar instability. *Skeletal Radiol*. 2009; 38:329–338.

27. Vahasarja V, Lanning P, Lahde S, Serlo W. Axial radiography or CT in the measurement of patellofemoral malalignment indices in children and adolescents? *Clin Radiol*. 1996;51:639–643.
28. van Huyssteen AL, Hendrix MR, Barnett AJ, Wakeley CJ, Eldridge JD. Cartilage-bone mismatch in the dysplastic trochlea: an MRI study. *J Bone Joint Surg Br*. 2006;88:688–691.
29. Wagenaar FC, Koeter S, Anderson PG, Wymenga AB. Conventional radiography cannot replace CT scanning in detecting tibial tubercle lateralisation. *Knee*. 2007;14:51–54.
30. Wittstein JR, Bartlett EC, Easterbrook J, Byrd JC. Magnetic resonance imaging evaluation of patellofemoral malalignment. *Arthroscopy*. 2006;22:643–649.