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Re-evaluating the functional implications of the Q-angle and its relationship to in-vivo patellofemoral kinematics

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Abstract

Background—The Q-angle is widely used clinically to evaluate individuals with anterior knee pain. Recent studies have questioned the utility of this measure and have suggested that a large Q-angle may not be associated with lateral patellofemoral translation, as often assumed. The objective of this study was to determine: 1) how accurately the Q-angle represents the line-of-action of the quadriceps and 2) if adding active quadriceps contraction or a bent knee position to the measurement of the Q-angle improves its reliability, accuracy, and association with patellofemoral kinematics.

Design—Cross-sectional cohort study.

Methods—The study included individuals diagnosed with chronic idiopathic patellofemoral pain and control subjects (n=43 and n=30 knees). Three measures of the clinical Q-angle (straight- and bent-knee with relaxed quadriceps and straight-knee with maximum isometric quadriceps contraction) were obtained with a goniometer and compared to a fourth MR-based measure of Q-angle. Patellofemoral kinematics were derived from dynamic cine-phase contrast images, acquired while subjects extended/flexed their knee from approximately 0° and 45°.

Findings—The Q-angle did not represent the line-of-action of the quadriceps. The average difference between each clinical and the MR-based Q-angle ranged from 5° to 8°. These differences varied greatly across subjects (range: −28.5° to 3.9°). Adding an active quadriceps contraction or a bent knee position, did not improve the reliability of the Q-angle. An increased Q-

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angle correlated to medial patellar displacement and tilt ($r = 0.38\text{--}0.54$, $p < 0.001$) in the cohort with anterior knee pain.

Interpretation—Clinicians are cautioned against using the Q-angle to infer patellofemoral kinematics.

Keywords

patellofemoral joint; patellofemoral pain syndrome; magnetic resonance imaging; kinematics; knee

INTRODUCTION

Chronic idiopathic patellofemoral (PF) pain affects 14–17% of the young active population (Boling et al., 2009; Iwamoto et al., 2008) and is typically exacerbated by activities such as stair ascent/descent, prolonged sitting with flexed knees, jumping, and open-chain extension exercises (Thomee et al., 1995). The Q-angle (Aglietti et al., 1983; Insall et al., 1976) is often used, in conjunction with several other common clinical measures (e.g., patellar glide test and J-sign), to identify contributing factors to PF pain/instability (Draper et al., 2011; Grelsamer et al., 2005; Johnson et al., 1998; Lan et al., 2010; Mulford et al., 2007; Sheehan et al., 2009), guide rehabilitation, and plan surgical interventions (Endres and Wilke, 2011; Feller et al., 2007). However, this measure has been subject to substantial controversy over its clinical utility (Park and Stefanyshyn, 2011), reliability (Wilson, 2007), and relationship to PF kinematics (Ortqvist et al., 2011; Sheehan et al., 2009). These controversies may have arisen from the fact that the Q-angle (Figure 1) was originally defined as “the angle between the line-of-application of the quadriceps force and the direction of the patellar tendon force” (Hungerford and Barry, 1979). “The line-of-application of the quadriceps force” was defined as the direction of pull for the quadriceps tendon. Yet, in current clinical practice, the Q-angle is defined as the 2D acute angle formed by two vectors extending from the anterior mid-patella to the anterior superior iliac spine (ASIS) and tibial tuberosity. This clinical definition rests on the untested assumption that the “line-of-application of the quadriceps force” can be approximated by a vector from the anterior mid-patella to the ASIS. To substantiate the clinical utility of the Q-angle, the validity of this assumption must be demonstrated.

The relationship between the Q-angle, quadriceps force, and PF kinematics is based on the model that assumes alteration in the force balance around the knee leads to altered PF kinematics (“patellar maltracking”), which ultimately contributes to PF pain. A large Q-angle ($> 15^\circ$) is thought to indicate excessive lateral quadriceps force (Emami et al., 2007; Wunschel et al., 2011), resulting in disproportionate lateral patellar displacement during dynamic activities involving quadriceps muscle activity (Bourne et al., 1988; Fredericson and Yoon, 2006; Mizuno et al., 2001; Post, 1999). Forces on the patella are primarily generated by the quadriceps force, the femoral sulcus, and ligamentous forces. Measuring the Q-angle with the leg fully extended and the quadriceps relaxed (Bourne et al., 1988; Fredericson and Yoon, 2006; Post, 1999) limits the influence these forces have on the patellar position. Thus, voluntary quadriceps activation or the addition of knee flexion, to better engage the patella within the sulcus groove during the measurement of the Q-angle,

may strengthen the Q-angle's relationship to *in vivo* patellar kinematics and by doing so improve its reliability and utility.

There is scant evidence (Mizuno et al., 2001) to support a relationship between the Q-angle and lateral patellar maltracking. Orqvist and colleagues (2011) reported no correlation between the Q-angle and lateral patellar displacement in an asymptomatic adolescent population. Sheehan and colleagues (2009) reported that the Q-angle was correlated with *in vivo* medial, not lateral, patellar displacement in a cohort of subjects with PF pain. Freedman and Sheehan (2013) confirmed this finding using a new MR-based rectus femoris Q-angle (RF-Q-angle) measure that incorporated the true line-of-application of quadriceps force. Although the clinical use of the RF-Q-angle is limited, it provides a gold standard (Hungerford and Barry, 1979) for evaluating the accuracy of the clinical Q-angle.

Therefore, the purpose of this study was to determine if the clinical Q-angle represents the true line-of-application of the quadriceps force, as measured by the RF-Q-angle, in cohorts of healthy individuals and individuals with PF pain. A secondary purpose was to determine if the reliability of the clinical Q-angle and its correlation to PF kinematics could be improved by incorporating two separate factors (active quadriceps and knee flexion) into the measurement. Three supine testing positions were utilized (a straight leg with quadriceps relaxed; straight leg with maximum isometric quadriceps contraction; and a bent knee positioned at 15° flexion with quadriceps relaxed).

2. METHODS

Two cohorts consisting of individuals with and without PF pain were recruited as samples of convenience for this IRB-approved study (Intramural IRB of the National Institute of Child Health) from ongoing studies at National Institutes of Health, three local orthopaedic clinics, a physical medicine and rehabilitation clinic, and self-referral based on the clinical trials website. All subjects provided informed consent (or assent if a minor with a legal guardian providing consent). Any potential participant, regardless of cohort, who had (1) prior limb surgery; (2) ligament, meniscus, iliotibial band, or cartilage damage at the knee; (3) other lower leg disorder or injury; or (4) traumatic onset of PF pain syndrome was excluded from the study. The first cohort (Table 1) consisted of volunteers diagnosed with chronic (>6 months) idiopathic PF pain and no history of lower limb surgery. These volunteers had at least one marker of maltracking (lateral hypermobility 10mm, Q-angle 15°, and/or the presence of a J-sign) (Sheehan et al., 2009). Both knees were included within the study if they met the inclusion criteria, resulting in a final cohort of 43 knees, from 32 subjects (Table 1). Subjects rated their pain (Table 1) using the anterior knee pain score (AKPS) (Kujala et al., 1993) and a visual analog scale (VAS), based on an average day over the past two weeks (Thomee et al., 1995). The second cohort (n=30) was an asymptomatic population with no history of lower leg pain, injury, surgery, or pathology, in which a single knee was selected at random for inclusion (Table 1).

2.1 Clinical Measures (Q-angle)

A physical therapist measured the Q-angle in three ways while the subject lay supine with: 1) the hip and knee fully extended and the quadriceps fully relaxed (Q-AI); 2) the hip and

knee fully extended and with maximum isometric quadriceps contraction (Q-AII); and 3) the knee bent to 15° with the quadriceps relaxed (Q-AIII). Subjects were instructed to keep all muscles, but particularly the leg muscles, relaxed while QA-I and Q-AIII were measured. To assess QA-II, individuals were instructed to perform maximum isometric quadriceps contraction (against a resistance applied to the tibia) while the measurement was made. The absence or presence of muscle contraction was visually and tactilely verified while the Q-angle was measured. For Q-AIII, the subject's knee was positioned at 15°, measured with a goniometer, by placing an adjustable cushion under the knee.

One physical therapist (author TJB) acquired the clinical Q-angles for subjects of both cohorts recruited in the approximate first half of the study. This therapist had 19 years of experience as a physical therapist and 20 as an athletic trainer at the time of the study. As this therapist transitioned out of the lab prior to the end of the study, he trained a second physical therapist (PT, PhD with 21 years of experience) in the lab's methodology for acquiring the Q-angle, to maintain consistency across the study. The second physical therapist then acquired the clinical Q-angle measures for the subjects recruited during the approximate second half of the study.

2.2 Reliability for the Clinical Q-angle measures

Both physical therapists involved in acquiring the measures of the clinical Q-angle participated in an intra- and inter-rater reliability study. A separate control population (15 subjects) was recruited solely for the reliability arm of the study and this cohort did not participate in any MR imaging. Both knees were evaluated for each subject in this control cohort, for a total of 30 knees. All three clinical Q-angle measures were measured twice (on two separate days) by each therapist. Both therapists were blinded to all previous measures. To limit bias, a minimum of 48 hours between measures on a single subject was maintained. The subject order was randomized for each visit and each physical therapist. A separate investigator (author BRF) recorded the Q-angle to limit visual memory. Intra- and inter-rater reliability for the three clinical Q-angle measures was evaluated based on intra-class correlation coefficients (ICCs), using a two-way mixed effects model.

2.3 Magnetic Resonance Imaging

Following the clinical examination, subjects (excluding the control subjects in the reliability study) participated in both static and dynamic MR imaging (Figure 2). For the static scanning, subjects were positioned supine within a 3-Tesla MR scanner (Philips Electronics, Eindhoven, the Netherlands). The subject's leg was fully extended in an anatomically neutral position with their knee in an 8-channel knee coil. Subjects were instructed to relax all muscles while sagittal T1-weighted high resolution 3D gradient recall echo (GRE) images were taken and then converted to an axial image set (0.27mm × 0.27mm × 1mm). The imaging planes were positioned from just distal to the tibial tuberosity to just superior of the distal rectus femoris (RF) myotendinous junction.

For dynamic image acquisition, the subject's knee was placed inside of a customized coil holder with phased array coils medial, lateral, and anterior of the knee. A cushioned wedge was placed under the knee, supporting both the knee and hip in slight flexion. Subjects

actively extended and flexed their knee, against the weight of the lower leg, from $\sim 45^\circ$ flexion to terminal extension guided by the beat of an auditory metronome (30 cycles per minute with 2 beats per cycle) for 2.0 minutes. Subjects practiced the task prior to image capture. During the cyclic movement dynamic cine-PC MR images were acquired (sagittal-oblique plane, x, y, z, velocity and anatomic images over 24 time frames). Three-dimensional patellar kinematics (Figure 3) were analytically quantified through integration of the cine-PC MR data (accuracy < 0.33 mm) (Behnam et al., 2011). Patellar kinematics were expressed relative to an anatomically-based femoral coordinate system (Seisler and Sheehan, 2007). Medial, superior, and anterior displacement along with flexion, medial tilt, and varus were defined as positive. All rotations were calculated based on an xyz-body fixed Cardan rotation sequence (Sheehan and Mitiguy, 1999). To remove subject size as a confounding variable, patellar displacement was scaled by the ratio of the average epicondylar width from a previous control cohort (Seisler and Sheehan, 2007), to the subject-specific epicondylar width.

The RF-Q-angle (Freedman and Sheehan, 2013) was defined as the 2D acute angle in the coronal plane between two vectors beginning at the anterior mid-patella and extending to the RF myotendinous junction and to the tibial tuberosity (Figures 1 and 3). The anterior patella was defined as the most anterior patellar point in the mid-patellar image. The myotendinous junction was defined as the center RF muscle in the most distal axial image containing this muscle. The tibial tuberosity was defined as the mid-point of the patellar insertion into the tibia in the sagittal image containing the mid-tibial tuberosity. The investigator acquiring these measures (author BRF) was blinded to the subject's cohort enrollment during the analysis.

2.4 Statistical Analysis

An *a priori* power analysis (Faul, 2009) determined that 29 subjects were needed per group to determine a significant difference of 5° between the MR and clinical based measures of the Q-angle. This assumed a variability in the Q-angle similar to previous reports (Sheehan et al., 2009), an $\alpha = 0.05$, and a $\beta = 0.8$. Statistical significance was maintained at $p < 0.05$ for all statistical tests.

A two-way analysis of variance (ANOVA, SPSS 22.0, IBM Corporation, Somers, NY) was used to assess main and interaction effects of Q-angle type (QA-I, QA-II, QA-III, and RF-Q-angle) and cohort (control and PF pain) on the value of Q-angle. If significance was found, a Dunnett's 2-sided post-hoc test was completed. A two-tailed Student's t-test was used to compare the axial plane PF kinematics (medial shift and tilt) and demographics between cohorts. *P*-values were adjusted using a Bonferroni-type false discovery rate procedure (Benjamini Y., 1995).

Pearson's correlation coefficients were sought between all four Q-angle measures and the axial plane PF kinematics (patellar medial tilt and shift), evaluated at 10° of knee flexion. In a previous study (Freedman and Sheehan, 2013), a 10° knee flexion angle, based on MR images of the distal femur and proximal tibia, was equivalent to a 0° knee flexion angle, as measured clinically, using the lines from the hip center to the knee center and from the knee center to the ankle center. The correlations were calculated separately for each cohort.

3. RESULTS

No significant differences in demographics were observed between cohorts (Table 1). The cohort with PF pain demonstrated greater lateral and superior translation with excessive valgus rotation relative to the control cohort. At a knee angle of 10°, the cohort with PF pain was 1.9mm ($p=0.041$) and 3.6mm ($p=0.037$) more laterally and superiorly displaced with 1.1° ($p=0.007$) greater valgus rotation. All symptomatic subjects had idiopathic PF pain with duration of greater than 6 months (Table 1), but the entire cohort did not share any other intake parameter.

The three clinical Q-angles demonstrated moderate (Morton, 2000) intra- and inter-rater reliability ($ICC=0.52-0.74$, Table 2). This reliability was similar across the three clinical Q-angle measures, but well below that for the RF-Q-angle (Freedman and Sheehan, 2013).

The Q-angle was a significant main effect. The RF-Q-angle was smaller ($p<0.001$) than each of the three clinical angles (Figure 4). The cohort was not a main affect and there were no interaction effects. The differences between the clinical Q-angles and the RF-Q-angle varied greatly across subjects (range: -28.5° to 3.9°), with the coefficients of variation ranging from 0.63–0.95.

In the PF pain cohort, correlations between the Q-angle and PF kinematics were only found for the RF-Q-angle and Q-AIII (Figure 5). The correlations between Q-angles and PF kinematics were the strongest for the RF-Q-angle (medial shift: $r=0.54$, medial tilt: $r=0.48$). The correlations for Q-AIII were also with medial shift and medial tilt (Figure 5). In the control cohort, correlations were not found between the Q-angle and axial plane patellar kinematics.

4. DISCUSSION

Although the clinical Q-angle has been described as “an invaluable measure for those patients with PF pain” (Emami et al., 2007) the results of the current and past studies (Park and Stefanyshyn, 2011) question its use as a surrogate for patellar kinematics. The clinical Q-angle does not represent the true “line-of-application the quadriceps force;” it has low to moderate reliability (inter-rater $ICC=0.68$); does not strongly correlate to *in vivo* PF kinematics ($r=0.39$); the weak to moderate correlations with patellar kinematics that do exist demonstrate the opposite to what is commonly believed about the relationship between the Q-angle and patellar lateral displacement; and the Q-angle is not different between cohorts. The RF-Q-angle has similar limitations, with the exception of reliability. Its derivation was intended as a research tool to evaluate the accuracy of the clinical Q-angles, but not as a replacement for the clinical Q-angle. Even with all the suggested methodologies to improve its reliability (e.g. isometric quadriceps activation, bent knee, long arm goniometer (Draper et al., 2011), or centralizing the patella (Herrington and Nester, 2004)), the Q-angle by itself provides minimal insights in regards to *in vivo* patellar kinematics. Thus, clinicians are cautioned against using the Q-angle as a guide for rehabilitation management or invasive interventions.

As the RF-Q-angle and clinical Q-AI were both measured with the subject in as similar a position as possible; the average difference between these two variables represents the difference between using the vector from the anterior mid-patella to the ASIS as opposed to the true “line-of-application the quadriceps force” (Hungerford and Barry, 1979). If this difference (ranging from -28.5° to 3.9°) had been constant across subjects, then the clinical Q-angle would have been related to the true “line-of-application the quadriceps force,” with a simple correction factor or offset. Yet, this was not the case, as the variability in the difference was high. This was the likely reason that Q-AI was not correlated to the PF kinematics in either cohort. Such results imply that two patients with vastly different Q-angles may actually have identical lines of actions for their quadriceps.

Unexpectedly, the addition of a quadriceps load (Q-AII) or a bent knee position (Q-AIII) did not improve the reliability of measuring the Q-angle nor did it lessen the coefficient of variation of the difference between the RF-Q-angle and the clinical Q-angle. Adding the bent knee position strengthened the correlation between Q-AIII and PF kinematics, reinforcing the role of trochlear geometry on PF kinematics in individuals with PF pain (Harbaugh et al., 2010). Adding an isometric quadriceps contraction (Q-AII) did not strengthen the association between the clinical Q-angle and the patellar kinematics, indicating that an isometric contraction cannot fully emulate the dynamic state.

The lack of correlation between the Q-angle and PF kinematics (medial shift and tilt) within the control cohort is likely partially due to the smaller range in value of medial shift and tilt for this cohort, as compared to the cohort with PF pain. This lack of correlation agrees with the findings of Orqvist et al. (2011) who found no correlation between the static Q-angle and dynamic lateral patellar displacement during a single limb mini-squat test in pediatric subjects. In another study, Tsakoniti and colleagues (2008) found that healthy men with large Q-angles ($>15^{\circ}$) showed no difference in the ratio of cross sectional area between vastus lateralis and vastus medialis, when compared to men with a smaller Q-angle. Since the relative strength balance between these two muscle groups has been shown to influence patellar kinematics (Sheehan et al., 2012), the fact that no measurable changes in quadriceps muscle cross sectional area balance were observed for large variations in Q-angle measurements, provides further support for the Q-angle’s lack of correlation to patellar kinematics in control subjects.

Although the correlations in the cohort with PF pain appear contrary to long-held views on the relationship between the Q-angle and patellar kinematics, the results are easily explained by the Q-angle geometry (Grelsamer et al., 2005; Sheehan et al., 2009) and the shape of the PF sulcus (Harbaugh et al., 2010). In individuals with a high lateral femoral sulcus edge (Harbaugh et al., 2010), the patella is forced into a medial position by the sulcus, which tends to increase the Q-angle. On the opposite side of the spectrum, for individuals with a low lateral femoral sulcus edge (Amis, 2007) the femoral sulcus provides less constraint and allows the patella to displace laterally, reducing the Q-angle. The correlations in the cohort with PF pain disagreed with the study of Biedert and Warnke (2001). These researchers found no correlations between the Q-angle, as measured with long leg x-rays, and three static measures of patellar alignment (displacement, tilt, and patella-lateral condyle index). Since the average and standard deviation of the clinical Q-angles were similar between the

studies, the disagreement is likely due to the differences between patellar kinematics acquired during dynamic leg exercises and static clinical patellar alignment measures (Freedman and Sheehan, 2013). Mizuno and colleagues (2001) reported that the patella displaced laterally and tilted medially when the Q-angle was increased by lateralizing the RF proximal muscle origin. Yet, the variations in Q-angle are more likely due to changes in static patellar position (Figure 6), ligament laxity, femoral sulcus shape, and tibial tuberosity location, rather than variation in the superior insertion of the rectus femoris into the anterior inferior iliac spine (Grelsamer et al., 2005; Sheehan et al., 2009).

The primary limitation of this study was the fact that a single therapist did not evaluate all subjects. Even though the ICCs for the two physical therapists were some of the highest reported in the literature (Wilson, 2007), they remained below the level (0.90) required for “reasonable clinical validity” (Portney L., 2009). The variability this potentially introduced, may have contributed to the weaker correlations for the clinical Q-angles, as compared to the RF-Q-angle. Eleven subjects within the PF pain cohort demonstrated active growth (non-fused femurs, as observed on 3D fat-saturation GRE MR images). When these 11 knees were removed from the analysis, the study conclusions did not change. Finally, although PF pain is most often associated with activities requiring deep knee flexion, it is recognized that PF pain can be caused by both free knee extension (Thomee et al., 1995) and long term stationary sitting with flexed knees. The exercise used during dynamic imaging emphasized the conditions of joint instability by requiring a quadriceps force in terminal extension, where the femoral constraints on the patella are at a minimum and patellar maltracking is most evident (Brossmann et al., 1993; Sheehan et al., 2009).

5. CONCLUSIONS

Based the current results, one would question clinical procedures that focus on “*medializing*” the patella, particularly surgical ones, resting on the assumption that a large Q-angle accurately equates with excessive **lateral** displacement (Feller et al., 2007; Mizuno et al., 2001). Therefore, interventions are likely best guided by directly measuring *in vivo* patellar kinematics acquired during tasks requiring active quadriceps control using accurate dynamic measurement techniques (Behnam et al., 2011; Bey et al., 2008; Wilson et al., 2009). However, such methods are not readily available to most practicing clinicians. In such cases, clinicians may want to consider other clinical measures, such as the clinical patellar tilt angle (Grelsamer et al., 2008), that have demonstrated greater reliability and stronger correlations to patellar kinematics. Going forward we would recommend that the clinical Q-angle not be used as a surrogate for the patellar kinematics and that future research focus on developing clinical markers that have a strong relationship to patellar kinematics and/or PF pain.

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Highlights

- The data from the current study question the validity and utility of the Q-angle as it (1) does not represent the true “line-of-application the quadriceps force,” (2) has low to moderate reliability, (3) does not strongly correlate to in vivo PF kinematics, (4) has weak to moderate correlations with patellar kinematics indicating exactly the opposite of that believed clinically (medial displacement in increased Q-angle), and (5) was not different between cohorts.
- PF interventions are likely best guided by directly measuring in vivo patellar kinematics acquired during tasks requiring active quadriceps control using accurate dynamic measurement techniques.
- Clinicians may want to consider other clinical measures, such as the clinical patellar tilt angle, that have demonstrated greater reliability and stronger correlations to patellar kinematics.
- These study results lead to the recommendation that the clinical Q-angle not be used as a surrogate for the patellar kinematics. Future research should focus on developing clinical markers that have a strong relationship to patellar kinematics and/or PF pain.

FIGURE 1. Q-angle Definition

The three clinical Q-angle (CQ) measures were defined as the 2D acute angle between two vectors in the coronal plane extending from the anterior patella (PA) to the tibial tuberosity (TT) and the anterior superior iliac spine (ASIS). Three variations of the clinical Q-angle were assessed: **Q-AI**: knee in full extension, quadriceps relaxed, **Q-AII**: knee in full extension, quadriceps contracted, and **Q-AIII**: knee in 15° flexion, quadriceps relaxed. The RF-Q-angle (**RF-Q**) was defined similarly to Q-AI, except all measures were made using MR-images, and the center of the rectus femoris myotendinous junction (RF) was used to represent the true direction of pull of the quadriceps, with its origin at the anterior inferior iliac spine (AIIS) (Freedman and Sheehan, 2013).

FIGURE 2. Dynamic Magnetic Resonance (MR) Imaging Set-up

Subjects were placed in a supine position with their back resting on the plinth of the MR scanner. Phased-array transmit-receive coils were placed medial, lateral, and anterior to the knee. Subjects were asked to cyclically extend and flex their knee to the beat of an auditory metronome (2 beats/cycle with 30 cycles/min of movement). An optical trigger placed on the bed, below the ankle, synchronized the data collection to the motion cycle.

FIGURE 3. Coordinate System and RF-Q-angle Definitions

The static and dynamic coordinate systems were identically defined. The x-direction was directed medial. (A) In the mid-patellar axial image, the patellar x-direction was defined by the posterior-lateral edge and the patellar origin (Po) was defined as the most posterior point on the patella. (B) In the axial image at the level of the femoral epicondyles, the femoral x-direction was defined by the posterior femoral edge and the femoral origin (Fo) was defined as the deepest point in the sulcus. (C) The y-direction was directed superior. For the patella and femur, it was defined by the posterior patellar edge and the vector bisecting the angle created by the anterior and posterior femoral edges, respectively, in the mid-patellar sagittal image. Using cross-products, the z-axis (anterior) was created. The y-axis was adjusted slightly with the use of cross products so that each axis remained perpendicular to the other two. The 3D orientation angles (patellar flexion, tilt, and varus) were created using an xyz-body fixed Cardan Rotation sequence (Sheehan and Mitiguy, 1999). (A,C,D) After three regions of interest (ROIs) were chosen to represent the center of area of the myotendinous junction of rectus femoris (RF), anterior patella (PA), and tibial tuberosity (TT), the RF-Q-angle was computed (Freedman and Sheehan, 2013).

Figure 4. Differences in Clinical Q-angle relative to the RF-Q-angle

The mean difference between each of the clinical Q-angles (Q-AI, Q-AII, and Q-AIII) and the RF-Q-angle is provided as a column with error bars indicating one standard deviation. All clinical Q-angles were significantly different than the RF-Q-angle ($p < 0.001$, indicated by ** on the chart). None of the Q-angle measurements were significantly different between cohorts.

FIGURE 5. Correlations

Significant correlations in the cohort with PF pain between the Q-angles (RF-Q-angle, top row and Q-AIII, bottom row) and patellar kinematics (medial displacement, left column and medial tilt, right column). The x-axis is the value lateral (negative) to medial (positive) PF displacement or tilt at 10° knee flexion. The best linear fit is shown with a solid black line. Q-AI and Q-AII are not plotted as significant correlations were not found. No significant correlations were found for the control cohort between any Q-angle and patellar medial shift and tilt. The RF-Q-angle was weakly to moderately correlated with Q-AI, Q-AII, and Q-AIII ($r=0.50$, 0.48 , and 0.58 , $p<0.001$). The normative average is provided with a dashed line with a star indicating their intersection.

Figure 6. Effect of Patellar Displacement on Q-angle

The center image is a copy of Figure 1. For the images on the left and right, the patella was moved laterally and medially, respectively by the same amount. By moving the patella laterally (left image) the Clinical Q-angle (CQ) decreases to zero, whereas the RF-Q-angle (RFQ) becomes negative. When the patella is moved medially (right image) both CQ and RFQ become larger (more positive).

TABLE 1
Demographics and Clinical Scores

Asymptomatic Controls and Subjects with PF pain. The asymptomatic data was obtained prior to the patellar maltracking data, thus the clinical parameters were not collected for this cohort. A Student's t-test was used to compare means between groups. No significant differences ($P = 0.05$) were found between the group demographics. The number of subjects demonstrating a Q-AI $> 15^\circ$, Lateral Hypermobility $> 10\text{mm}$, and a J-sign is given. For the subjects with patellofemoral pain, 19 demonstrated one of these three markers, 18 demonstrated two of these markers and six demonstrated all three markers. SD - standard deviation; N/A – not applicable (data not collected).

Item	units	Asymptomatic	Subjects with PF pain
Demographics			
Gender	F/M	22/8	33/10
Age	years	25.2 (SD=7.4)	24.2 (SD=11.7)
Height	cm	165.8 (SD=9.1)	163.6 (SD=9.0)
Weight	kg	60.8 (SD=11.2)	59.2 (SD=11.2)
VAS	out of 100	N/A	35.8 (SD=24.3)
Kujala	out of 100	N/A	66.0 (SD=17.0)
Q-AI	deg	14 (SD=5)	15 (SD=5)
Q-AII	deg	13 (SD=5)	13 (SD=5)
Q-AIII	deg	15 (SD=5)	14 (SD=5)
RF-Q	deg	6.5 (SD=4.9)	6.4 (SD=6.5)
Intake Criteria			
Q-AI $> 15^\circ$	yes	N/A	20
Lateral hypermobility* $> 10\text{mm}$	yes	N/A	21
J sign present	yes	N/A	30
Duration of knee pain (years)	years	N/A	3.9 (SD=3.0)

TABLE 2

Intraclass correlation coefficients (ICCs) for the three measures of the clinical Q-angle. The 95% confidence interval is given below the ICC and is in parentheses.

Parameter	Clinical Q-angle I	Clinical Q-angle II	Clinical Q-angle III
Intra-rater 1	0.71 (0.45–0.85)	0.64 (0.36–0.82)	0.52 (0.18–0.74)
Intra-rater 2	0.72 (0.48–0.86)	0.52 (0.19–0.74)	0.74 (0.52–0.87)
Inter-rater	0.68 (0.52–0.81)	0.59 (0.41–0.76)	0.62 (0.45–0.78)