Effects of Isometric Quadriceps Activation on the Q-angle in Women Before and After Quadriceps Exercise

Laura H. Lathinghouse, MHS, PT
Mark H. Trimble, PhD, PT, OCS

Study Design: Single-group test-retest design with correlation analysis.
Objectives: (1) To confirm that the Q-angle decreases with isometric quadriceps activation (IQA), (2) to determine if the decrease in the Q-angle with IQA is related to the magnitude of the Q-angle at rest, and (3) to determine if a vigorous bout of exercise affects the change in the Q-angle with IQA.
Background: The Q-angle represents an estimate of the resultant force of the quadriceps on the patella and is a predictor of lateral movement of the patella under dynamic conditions.
Methods and Measures: Q-angles were assessed in 22 nonimpaired women (mean ± SD age, 22.3 ± 4.9 years) while standing relaxed and during IQA. Subjects then rode a cycle ergometer until a preset number of repetitions per minute was unable to be maintained. Q-angles were again assessed while subjects were relaxed and during IQA.
Results: There was a significant decrease (mean ± SD, 5.7 ± 4.2°) in the Q-angle with IQA compared with relaxed standing. There was a significant relationship (r = 0.72) between the Q-angle at rest and the change with IQA. The cycle ergometer exercise resulted in a small (0.5°) but significantly greater decrease in the Q-angle with IQA compared with relaxed standing.
Conclusions: The Q-angle decreases with IQA, and the magnitude of this decrease is dependent on the magnitude of the Q-angle at rest. Our findings support the view that an excessive Q-angle may predispose women to greater lateral displacement of the patella during vigorous activities and sports in which the quadriceps muscle is stressed. J Orthop Sports Phys Ther 2000;30:211–216.

Key Words: patellofemoral joint

The most commonly accepted cause for patellofemoral joint pain is abnormal patellar tracking. A common predictor of lateral subluxation of the patella is the quadriceps angle or Q-angle. The Q-angle represents the resultant force of the quadriceps femoris muscle group on the patella relative to the alignment of the patellar ligament. A common clinical estimate of this resultant force vector is made by a line connecting the anterior superior iliac spine (ASIS) to the midpoint of the patella; this vector is then related to the alignment of the patellar ligament from the midpoint of the patella to the tibia tubercle.

The Q-angle creates a lateral force vector on the patella and predisposes the patella to lateral displacement during activation of the quadriceps. The magnitude of this lateral force vector and the tendency for lateral displacement of the patella are believed to increase as the Q-angle increases. An increase in the Q-angle may also cause an increase in pressure between the patella and the underlying lateral femoral condyle during activation of the quadriceps.

Normal values of the Q-angle
have been shown to vary between 10 and 14° for men and 14 and 17° for women.\textsuperscript{1,9,21} Women have consistently been found to have larger Q-angles than men\textsuperscript{9,21} and are more often affected by patellofemoral problems.\textsuperscript{9} This is possibly due to an increased pelvic width,\textsuperscript{14} shorter femur length, or femoral neck anteversion.\textsuperscript{11} Some investigators have found that Q-angles greater than 15° for men and 20° for women are more commonly associated with pathological conditions of the patellofemoral joint.\textsuperscript{1,18}

Various factors can influence the magnitude of the Q-angle and thus the predisposition for lateral displacement of the patella. For example, subtalar joint pronation\textsuperscript{5,15,16} and internal femoral torsion\textsuperscript{11} have been shown to increase the Q-angle by altering the positions of patella and tibial tubercle relative to the ASIS. In contrast, subtalar joint supination and hip external rotation should decrease the magnitude of the Q-angle and decrease the tendency for lateral displacement.

As a result of the bowstring effect caused by the pull of the quadriceps in relation to the tibial tuberosity, activation of the quadriceps has been shown to decrease the Q-angle.\textsuperscript{8} Therefore, individuals with excessive Q-angles may be predisposed to greater changes in the Q-angle with isometric quadriceps activation (IQA). Although a slight decrease in the Q-angle with IQA would be expected, a substantial decrease may indicate the presence of an imbalance in the different heads of the quadriceps muscle. The oblique fibers of the vastus medialis are believed to provide an active counterbalance to the valgus forces on the patellofemoral joint.\textsuperscript{5,7,12} Relative weakness of the vastus medialis may increase the likelihood of the Q-angle to decrease and the patella to displace laterally with activation of the quadriceps.\textsuperscript{3,12}

Individuals with excessive Q-angles may be able to counteract the lateral pull on the patella by relative hypertrophy of the vastus medialis.\textsuperscript{20} Such individuals may still be at risk for greater degrees of lateral patellar subluxation, however, if fatigue of the quadriceps does not develop uniformly during exercise and strenuous activities. Deficits of the quadriceps mechanism may become evident by comparing the Q-angle with the quadriceps relaxed and with an IQA before and after vigorous exercise of the quadriceps muscles.

The purposes of this study are threefold. First, to confirm that a change occurs in the Q-angle with IQA. This has been shown in a previous study,\textsuperscript{8} but to our knowledge the results have not been replicated. Second, to determine if the decrease in the Q-angle with IQA is related to the magnitude of the Q-angle at rest. Third, to determine if a vigorous bout of exercise involving the quadriceps affects the Q-angle measurement during an IQA.

### METHODS

#### Subjects

Participants ($N = 22$) in this study were nonimpaired, pain-free women from the University of Florida and the Gainesville, Fla, community; their ages varied from 18–30 years (mean and SD, 22.3 ± 4.9 years). Only women were recruited for this study, because they generally have larger Q-angles and a higher incidence of patellofemoral problems.\textsuperscript{9,21} Exclusion criteria consisted of prior history of knee pathological conditions and cardiopulmonary problems. All participants read and signed a consent form that was approved by the Institutional Review Board of the Health Science Center at the University of Florida.

#### Procedure

Data collection required one testing session lasting 30–40 minutes per subject. Small reflective markers approximately 1 cm in diameter were applied to the right ASIS, midpoint of the right patella, and the midpoint of the right tibia tubercle for measurement of the Q-angle (Figure 1). The midpoint of the patella was determined by the intersection of a line from the medial to lateral patella and a line from the inferior to superior patella. Since the skin moved relative to the patella during IQA, use of a single mark for both conditions would have produced a considerable error in measurement. To account for movement of the patella relative to the skin, the midpoint of the patella was first marked with the quadriceps relaxed and then with the quadriceps contracted. Thus, 2 marks were made, and reflective tape was put over the mark for the condition being videotaped and then removed and placed over the other mark. In addition to moving the reflective tape, the midpoint of the patella was rechecked between test conditions. All testing was performed with subjects standing without shoes and with their knees in full extension. A video camera (Sony High 8) positioned in front of and perpendicular to the subject was used to record video images of the subject's lower extremity. The camera position was reassessed before each condition to ensure that it was level and perpendicular to the frontal plane of the subject's lower extremity.

Video data were acquired in standing with the quadriceps relaxed and while maintaining an IQA with the order of testing randomized. Subjects were instructed to stand with their feet shoulder width apart and parallel to each other with their weight evenly distributed over both feet. For the IQA condition, subjects were simply told to produce a strong quadriceps contraction and hold it for 5 seconds. The landmarks at the midpatella were reassessed after each condition to ensure skin movement did not
corrupt the Q-angle measurement. A standing position was chosen for 2 reasons. First, recent studies suggest no clinically significant difference exists between the Q-angle measured in standing and supine. Second, standing with weight bearing through the lower extremity represented a more functional position from which to measure the Q-angle.

The degrees of pronation and supination of the foot, hip anteversion and retroversion, and hip internal and external rotation have been found to affect the Q-angle. Although the degree of pronation and supination was not controlled and the presence of hip anteversion and retroversion was not determined in this study, the subject’s initial relaxed standing position was recorded by marking her foot position on the floor. The same position was then used throughout testing to ensure the same foot and leg position. If a subject’s Q-angle was influenced by these factors, we assumed the influence was similar on all measurements taken in standing.

Subjects exercised the quadriceps vigorously by riding a cycle ergometer for 5 minutes at 55% of their maximum heart rate as determined by the calculation $220 - \text{age}$. Subjects were then asked to maintain the pedaling frequency between 40 and 80 rpm, and the resistance to pedaling was increased to achieve 85–90% of maximum heart rate. Although subjects were allowed to drop below 40 rpm once, after they failed to maintain the pedaling rate a second time they were asked to stop. Subjects pedaled an average ($\pm SD$) of $239.5 \pm 89$ seconds at this intensity, achieving a pedaling frequency between 40 and 80 rpm. Immediately following this exercise, the subjects were filmed in the previously recorded standing position with the quadriceps contracted and then with the quadriceps relaxed. Although randomization of the order of IQA and relaxed conditions would have been preferred after the exercise conditioning (as was done before the exercise), the exercise effect would have been considerably diminished in the subjects in which the relaxed position was tested first.

One author (L.H.L.) made all Q-angle measurements using a video analysis system (IP Lab Spectrum by Scanalytics, Inc, Fairfax, Va) for the MacIntosh computer. Since these were static measurements, a single frame from each condition was taken at random with the frame grabber, and 5 measurements of the Q-angle were taken and averaged. A cursor, manually controlled with a mouse, was used to sequentially digitize the skin marker locations on the tibial tubercle, patella, and ASIS. The size of the cursor and skin marker were similar; thus, when the cursor was centered over the skin marker, it just covered it, allowing little variation for each measurement and reducing the potential for investigator bias influencing the data. The computer then drew lines connecting the cursor positions and calculated the angle between the line from the tibial tubercle to the patella and from the patella to the ASIS. To convert to Q-angle values, the angles between the 2 lines were subtracted from 180. This was done after a series of angles had been calculated. Intrarater reliability was assessed for 10 subjects by repeating the measurements of the Q-angle on different days using the same series of unmarked frames.

Analyses

To establish measurement reliability, an intraclass correlation coefficient was calculated for Q-angle measurements on different days. Specifically, a type 3,1 intraclass correlation coefficient was calculated using a 2-way (subject X trial) analysis of variance. To assess for changes in the Q-angle from rest to IQA, a 2-by-2 repeated-measures analysis of variance
The intrarater intraclass correlation coefficient equaled 0.98, indicating good reliability of our method of measurement. In addition, a post hoc analysis of the method error was calculated on the test-retest data and found to be 0.37. Method error is a measure of the discrepancy between 2 sets of repeated measures. It is calculated by dividing the SD of the difference scores (difference between measures 1 and 2) by the square root of 2.

The raw data and descriptive statistics are presented in the Table. The 2-way analysis of variance indicated significant main effects for state of contraction (mean decrease = 5.6 ± 4.3°, $F_{1,18} = 32.44, P < .001$) and exercise (mean decrease = 0.5 ± 1.3°, $F_{1,18} = 7.60, P < .02$). There was no interaction, however, between the state of contraction and the effect of exercise. The mean (±SD) decrease in the Q-angle with IQA compared with relaxed standing was 5.3 ± 4.3° before exercise and 5.8 ± 4.4° after exercise in the 19 subjects who performed the cycle ergometer exercise (Figure 2). There was a statistically significant correlation ($r = 0.72$, slope = 1.48, $P < .05$) between the Q-angle at rest and the change in the Q-angle with IQA (Figure 3).

DISCUSSION

The results of this study support earlier findings of Guerra et al. that the Q-angle decreases with IQA. In
addition, we demonstrated that the magnitude of the decrease with IQA increases as the magnitude of the Q-angle in relaxed standing increases (Figure 3).

Thus, our findings support the view that an excessive Q-angle may predispose women to greater lateral displacement of the patella during vigorous activities and sports in which the quadriceps is stressed. Excessive lateral displacement of the patella with quadriceps activation could be interpreted as a patellar tracking error, which has been hypothesized as being a potential cause of patellofemoral pain.

The association between the Q-angle at rest and the decrease with IQA was $r = 0.72$ ($R^2 = 0.52$). Only 52% of the variance in the Q-angle with IQA was accounted for by the Q-angle at rest. Other factors not measured accounted for 48% of the observed variance. Factors such as the relative strength of the various components of the quadriceps, the depth of the intertrochlear groove, the shape of the patella, and the presence of patella alta may explain why some individuals with high Q-angles at rest show little difference when the quadriceps are isometrically activated and other individuals with normal Q-angles at rest show a considerable decrease.

The level of quadriceps activation during testing may also influence the degree to which the Q-angle changes with IQA. In our study, the level of quadriceps activation was not controlled. The results may have been different if the level of quadriceps activation was consistently near maximal for all subjects.

Muscle fatigue may also change the relative balance between the different heads of the quadriceps if the muscles do not fatigue uniformly. We demonstrated a small but significant effect of exercise; that is, the Q-angle decreased more with IQA after the cycle ergometer exercise than before it. The magnitude of this change (0.5°), however, may not have clinical or practical significance, because the magnitude was only slightly greater than our calculated method error of 0.37°.

There are several possible reasons why the effect of exercise was so small; 2 of the most pertinent reasons will be discussed. First, since the level of quadriceps activation was not controlled, it was likely that several if not most of the subjects activated the quadriceps submaximally during the IQA condition. Furthermore, if considerable quadriceps fatigue developed following exercise, the subjects may not have been able to generate a maximal contraction. Regardless of the reason, differences in the level of quadriceps activation before exercise may have led to the patella not moving as far laterally with IQA as it may have after the exercise. Second, our choice of quadriceps exercise may also have limited the effect of exercise. Use of a cycle ergometer to induce quadriceps fatigue was an acknowledged limitation of our study. Cardiovascular fatigue may have been more of a limiting factor than fatigue of the quadriceps when pedaling the cycle ergometer. There are alternative methods to induce muscle fatigue with less cardiovascular fatigue such as with an isokinetic dynamometer.

Replication of this study using an exercise in which quadriceps fatigue can be documented and the level of quadriceps activation is monitored before and after exercise is justified. Such a design would also allow for relative changes in the levels of activation of the various quadriceps muscles before and after exercise to be related to the change in the Q-angle.

CONCLUSIONS

Although the magnitude of the Q-angle at rest has been used to indicate the predisposition to patellar tracking errors during functional activities, measuring the change in the Q-angle with IQA compared with the resting Q-angle may enhance a clinician’s ability to predict which individuals are at greatest risk of developing patellar tracking and patellofemoral dysfunction. A prospective study in which these measures are taken on a population at risk, such as junior high-aged and high school-aged girls, and then correlating these measures with the incidence of patellofemoral dysfunction would test this supposition. Determining if a group of patients with patellofemoral dysfunction demonstrates greater changes in the Q-angle with IQA is also warranted.

REFERENCES

5. D’Amico J, Rubin M. The influence of foot orthoses on...