Research Report

Does the Q Angle Reflect the Force on the Patella in the Frontal Plane?

**Background and Purpose.** The quadriceps femoris muscle angle (Q angle) is used to reflect the quadriceps femoris muscle's force on the patella in the frontal plane. We found no studies, however, that validate this assumption. The purpose of this study was to determine whether the Q angle can be used to represent the force on the patella in the frontal plane. **Subjects.** Seven lower extremities from four male cadavers were dissected and investigated. **Methods.** We devised a model in which the line of action of quadriceps femoris muscle's resultant force was calculated in the frontal plane on the seven lower-extremity specimens. We then compared these calculations with the Q angles from the same cadaver specimens. The differences between the measured and calculated Q angles were tested for significance using a paired t-test. In addition, we calculated a simple linear regression to test the relationship between the calculated and measured Q angles. **Results.** Our data showed that the angle for the average resultant force of the quadriceps femoris muscle was 3.90 degrees greater ($P = .0003$) than the measured Q angles. A significant relationship ($r = .919, P = .0035$), however, was found between the measured and calculated Q angles. **Conclusion and Discussion.** The Q angle, as measured in clinical practice, appears to reflect the angle of the resultant quadriceps femoris muscle force. We believe, however, that this measurement is significantly less than the actual quadriceps femoris muscle force vector and underestimates the lateral force on the patella. [Schulthies SS, Francis RS, Fisher AG, Van De Graaff KM. Does the Q angle reflect the force on the patella in the frontal plane? Phys Ther. 1995;75:24–30.]

**Key Words:** Biomechanics, Knee, Patellofemoral, Q angle, Validity.

The angle formed by the resultant force of the quadriceps femoris muscle on the base of the patella and the line of pull of the patellar ligament on the apex of the patella is called the "Q angle." In clinical practice, the Q angle is measured by drawing an imaginary line from the anterior superior iliac spine (ASIS) to the center of the patella and from the center of the patella to the tibial tuberosity (Fig. 1). The acute angle formed by these two lines is the measured Q angle. An abnormally high Q angle is one of the main purported causes of patellofemoral pain and instability. Several studies have been conducted to determine norms for the Q angle (ranging from 10° to 14° for male subjects and from 14.5° to 17° for female subjects) and to establish the reliability (ranging from .76 to .92, using Pearson Product-Moment Correlation Coefficients and intraclass correlation coefficients) of various measuring tech-
describe the Q angle. He defined the measuring the Q angle using the Physical Therapy/Volume 75, Number January 1995 Brattström was the first to define and techniques. To date, however, the validity of the Q angle as a measure of the angle of the quadriceps femoris muscle's resultant force on the patella and tibial tuberosity has not been addressed.

Brattström was the first to define and describe the Q angle. He defined the Q angle as an angle with its apex at the patella formed between the ligamentum patellae and the extension of the line formed by the quadriceps femoris muscle's resultant force. Insall et al described the technique for measuring the Q angle using the ASIS as its proximal landmark. For calculation of the Q angle, the ASIS is therefore used to approximate the angle of the quadriceps femoris muscle's resultant force, yet no studies have been conducted to validate this approximation. The questionable validity of the measured Q angle lies in the assumption that the line from the ASIS provides an accurate approximation of the quadriceps femoris muscle's resultant force. The validity of the measured Q angle can be tested by comparing the Q angle as measured by a standard clinical method (using the ASIS as the proximal reference) with the calculated Q angle (using the quadriceps femoris muscle's resultant force as the proximal reference).

The purpose of this study was twofold: (1) to develop a static model of the quadriceps femoris muscle by which the muscle's resultant force in the frontal plane could be accurately calculated and (2) to compare the Q angle measured using the ASIS as the proximal reference with the Q angle using the quadriceps femoris muscle's resultant force as the proximal reference on the same cadaver specimens.

Previous Quadriceps Femoris Muscle Models

The quadriceps femoris muscle has usually been described using either muscle-directed models (straight-line or centroid models) or fiber-directed models. Muscle-directed models describe the muscle's force as a line connecting the muscle's origin and insertion or a line represented by the centroid of multiple muscle cross sections. In order for muscle-directed models to be valid, several assumptions must be met. First, a muscle's attachments must be sufficiently defined to enable a person to reduce the muscle fibers' multiple forces into one discrete force. The large area of origin of the vastus medialis (VM) and vastus lateralis (VL) muscles, however, makes it difficult to locate a single point of origin for each muscle. Models of the quadriceps femoris muscle, therefore, must divide the VM and VL into multiple components to accurately describe their forces. Second, muscle-directed models assume that the forces developed by muscles are in line with their longitudinal axes (ie, the muscle fiber forces are uniformly distributed around a muscle's longitudinal axis, or other forces exist, to ensure a zero net lateral movement of a muscle's longitudinal axis). This assumption, however, is not completely true in the quadriceps femoris muscle. Muscles develop force in line with the direction of their individual fibers, which may or may not be the same direction as the muscle's longitudinal axis.

To determine the force in line with the longitudinal axis of a pennate muscle, the force generated by the muscle fibers must be multiplied by the cosine of the angle of pennation.

\[ M = F \times \cos \phi \]

where \( M \) = the force vector of the muscle, \( F \) = the force vector of the muscle fibers, and \( \phi \) = the angle of pennation.

The force pulling perpendicular to the longitudinal axis of the muscle, determined by multiplying the muscle force by the sine of the angle of pennation, is often ignored. Figure 2 shows the vector arrangement of a bipennate muscle. Vector I can be ignored because the two vectors are equal in magnitude and opposite in direction. Figure 3 represents the vector arrangement of a unipennate muscle (eg, VL). In this type of muscle, vector I should not be ignored when developing a biomechanical model of the muscle force. In order to neutralize vector I, a vector of equal magnitude and opposite direction must be present. In humans, the vector I of the VM must be neutralized by pull from the VM (Fig. 4). Based on the many cases of quadriceps femoris muscle dysplasia and patellar tracking disorders, it appears that the vector I of the VM is not equal to the vector I of the VL. Therefore, models of the quadriceps femoris muscle should not be based on the direction of the longitudinal axis of the muscle alone but should also take into ac-

![Figure 1. Q angle (angle APT') as measured by a standard clinical method. (A=anterior superior iliac spine, P=center of patella, T=tibial tuberosity, T'=point of proximal extension of line PT).](image-url)
count the direction of the muscle fibers. This is especially true for the distal portion of the quadriceps femoris muscle, where the patella and quadriceps femoris muscle's tendon are free to glide medially and laterally when the knee is in an extended position. In the proximal portion of the quadriceps femoris muscle, the VL and VM blend with the vastus intermedius muscle (VI); their tendons are more securely anchored, and the muscle-directed model appears to be valid.

In 1968, Lieb and Perry\textsuperscript{14} described five functional components of the quadriceps femoris muscle, based on the direction of their fibers: VL, rectus femoris muscle (RF), VI, vastus medialis longus muscle (VML), and vastus medialis oblique muscle (VMO). The VM was divided into oblique and long portions because of the "marked and abrupt change in fiber alignment between its superior and inferior portions."\textsuperscript{14} In 1984, Scharf et al\textsuperscript{20} corroborated many of Lieb and Perry's findings using the femoral shaft as their reference. Of 32 cadaver specimens, Scharf et al determined the average deviation of each component of the quadriceps femoris muscle in the frontal plane.

The models proposed by Lieb and Perry\textsuperscript{14} and Scharf et al\textsuperscript{20} also contain drawbacks. First, although the VM was divided into long and oblique portions, no attempt was made to divide the VL. Second, no attempt was made to measure the force production capability of the different components. We devised what we believe is a more complete model.

**Current Model Description**

We used a combination of muscle-directed and fiber-directed models. We modeled the distal vastus muscles according to the direction of the muscle fibers. We modeled the proximal vastus muscles and the RF according to the muscles' longitudinal axes.

**Division of the Quadriceps Femoris Muscle into Components**

We divided the quadriceps femoris muscle into eight components, with one component consisting of the RF and with the vastus muscles divided into seven components (Fig. 5). Component 1 consisted of the most distal portion of the VM, originating from the adductor magnus muscle's tendon and the medial intermuscular septum and inserting on the superior medial border of the patella. Component 2 consisted of the middle portion of the VM, originating from the adductor magnus muscle's tendon, the adductor longus muscle's tendon, and the medial intermuscular septum and inserting into the movable portion of the quadriceps femoris muscle's tendon below the insertion of the distal fibers of the VI. Component 3 consisted of the proximal portion of the VM, originating from the linea aspera and inserting into a long tendon running proximally up the thigh and dividing the VM and VI. Component 4 consisted of the VI. Component 5 consisted of the proximal portion of the VL, originating from the linea aspera and the fascia lata and inserting into a tendon dividing the VL and VI. Component 6 consisted of the middle portion of the VL, originating from the linea aspera and the fascia lata and inserting into the quadriceps femoris muscle's tendon below the insertion of the oblique portion of the quadriceps femoris muscle's tendon.
Muscle Force Generation

During contractions of full-effort knee extension, the main determining factor of each quadriceps femoris muscle component's force production is its physiological cross-sectional area (PCSA)\(^{16-20}\).

Alexander and Vernon\(^{16}\) devised an equation by which a muscle's cross-sectional area and force production could be calculated. If a muscle has a mass of (m) and a known density of (p), the volume (V) is

\[
V = \frac{m}{p}
\]

If the average fiber length (l) is known, then

\[
PCSA = \frac{V}{l}
\]

or

\[
PCSA = \frac{m}{pl}
\]

The maximum isometric force production of the muscle is equal to the summated maximal isometric force production of the fibers (F), which can be determined by

\[
F = PCSA \times MFC
\]

where MFC = the muscle force constant that relates a muscle's PCSA to its maximal isometric force generation capability.

If equation 4 is substituted into equation 5, the maximal isometric force can be calculated by

\[
F = \frac{m}{pl} \times MFC
\]

The force production of fusiform muscles is calculated according to equation 6. If the muscle is bipennate or unipennate, the PCSA can be calculated according to equation 4. The muscle force (M), however, does not equal the summated fiber force (F) but is found by

\[
M = \frac{m}{pl} \times MFC \times \cos \phi
\]

Discrepancies exist concerning the actual value of MFC due to the large variations in species, type of contraction, and criteria for determining PCSA. Herzog\(^{18}\) adjusted Haxton's\(^{17}\) original data to negate the effect of pennation angle and calculated values of MFC between 35.7 and 37.4 N/cm\(^2\). In accordance with the purpose of our study, the absolute value of MFC is of little importance as long as the same value of MFC is used uniformly throughout the study. We arbitrarily used 37 N/cm\(^2\) as the MFC in calculating the force of each quadriceps femoris muscle component.
Method

One author (SSS) measured Q angles on seven human cadaver thigh specimens using the ASIS as the proximal landmark (as described in the literature \(36,8-10\)) and compared the results with the Q angles calculated using the direction of the quadriceps femoris muscle's resultant force as the proximal landmark. All other landmarks (ie, center of patella and tibial tuberosity) were identical. The quadriceps femoris muscle's resultant force line of action was calculated in the frontal plane from the PCSAs and directions of pull of the different components of the quadriceps femoris muscle as described previously.

Specimens

We selected four embalmed male cadavers as specimens. We examined both thighs on each cadaver, except one, making a total of seven thighs investigated.

Testing Procedure

We placed each cadaver supine on the examination table with the feet perpendicular to the floor and with the knees fully extended. We stabilized the feet with the lateral malleoli the same distance apart as the greater trochanters. This was accomplished by inserting an appropriate-length 2.54 x 10.16-cm (1 x 4-in) board between the medial borders of the feet. The feet were then bound securely to the board with string. We removed skin and subcutaneous fat from the thigh and exposed the proximal femoral shaft. Location markers were placed over (1) the center of the patella, (2) the tibial tuberosity, (3) the center of the proximal femoral shaft, and (4) the ASIS. Strings were attached to the markers, and measurements were then taken of angles APT' (ASIS→center of patella→imaginary proximal point in line with the patellar tendon) and FPA (femoral shaft→center of patella→ASIS) using a handheld goniometer (Fig. 6).

We divided each muscle into its individual components as described earlier. Location markers and strings were then attached to each component in line with the superficial muscle fibers in components 1, 2, 6, and 7 and in line with the muscles' longitudinal axes in components 3 and 5. Location markers with connecting strings were placed in the middle of the patella and the anterior inferior iliac spine for component 8. The femoral shaft represented the line of pull of component 4. Using a handheld goniometer, we took measurements of each component's deviation from the femoral shaft in the frontal plane (Fig. 5). Each component was then carefully removed from the thigh and weighed using a triple-beam balance.*

Fiber lengths were then measured using a ruler. For components 3 and 5, we measured pennation angles (angle between the insertional tendon and muscle fibers) using a handheld protractor. For components 6 and 7, a facial plane divided the superficial and deep portions of the muscle. The angle between the muscle fibers and this facial plane was measured using a handheld protractor. The pennation angle was then recorded as the pennation angle. Component 8 was divided from front to back throughout the length of the muscle in order to reveal the central tendon. The pennation angle was then again measured using a handheld protractor. Because a substantial amount of variation was found in the pennation angles and fiber lengths, we took between three and six measurements (depending on the variability observed) and calculated averages.

We calculated the force production capability of components 1 and 2 using equation 6, and we calculated the force production of components 4 through 8 using equation 7. We then summed the force vectors of the eight components to obtain the final quadriceps femoris muscle resultant force relative to the femoral shaft (line VP in Fig. 6). Angles lateral to the femoral shaft were assigned positive values, and angles medial to the femoral shaft were assigned negative values. Because we computed the quadriceps femoris muscle force vector in relation to the femoral shaft, we added angles FPA and APT' to the resultant force (angle VPF) to derive the magnitude of the calculated Q angle (angle VPT'). We then compared this measurement with the measured Q angle (angle APT').

Data Analysis

We performed a paired t test to test for differences between the measured Q angle and the calculated Q angle. In addition, we performed a simple linear regression to calculate the relationship between the measured and calculated Q angles.

Results

Averages and standard deviations of the (1) fiber length, (2) mass, (3) pennation angle for each component, and (4) angle of deviation from the femur are shown in Table 1. Calculated Q angles, measured Q angles, and differences for each specimen are presented, along with their averages, in Table 2. The Q angle calculated using the quadriceps femoris muscle's resultant force as the proximal landmark was an average of 3.90 degrees greater \((t=7.59, P=.0003)\) than that measured using the ASIS as the proximal landmark. A significant \((F=26.98, P=.0035)\) and very strong linear relationship existed between the measured and calculated Q angles \((r=.919, R^2=.844)\).

Discussion

This study used a combination of muscle-directed and fiber-directed models to determine the quadriceps femoris muscle's resultant force in the frontal plane. We used muscle-directed modeling on the proximal portion of the vastus musculature (components 3–5) and the RF (com-
Our results suggest that the actual force vector of the quadriceps femoris muscle is more laterally directed than the ASIS. Clinical measurements of Q angle, therefore, may underestimate the magnitude of the lateral force affecting the patella. Using the average quadriceps femoris muscle force calculated in this study (5,773.07 N), we calculated the lateral force on the patella, using the ASIS to determine the direction of the quadriceps femoris muscle's resultant, to be 1,636.81 N. We then calculated the lateral force on the patella using our calculated quadriceps femoris muscle's resultant as the proximal arm of the Q angle and found it to be 2,024.18 N. According to these calculations, the Q angle underestimates the lateral force on the patella by 387.37 N or 19.14%.

Because the Q angle may underestimate the actual forces on the patella, the clinical relevance of the measurement can be challenged. We believe, however, that the Q angle, as measured in our study, is clinically useful. Changes in the anatomical relationship of the patella, tibial tuberosity, femur, and pelvis will change the forces acting on the patella. This change is evidenced by the high correlation that we found between the measured and calculated Q angles. An $R^2$ value of .844 suggests that approximately 84% of the variation of the direction of the quadriceps femoris muscle's force on the patella in the frontal plane could be explained by variation in the measured Q angle.

Our findings support the importance of careful inspection and functional evaluation of the VMO and VI, in addition to measuring the Q angle, when evaluating a patient with patellofemoral pain. Our findings also suggest that the actual force on the patella may be "abnormally" laterally directed even in the presence of a "normally" measured Q angle. Cadaver specimen 11, for example, had a measured Q angle of 15 degrees, whereas we calculated the Q angle using the quadriceps femoris muscle's resultant force to be 20.8 degrees. We also found evidence of the body's adaptation for abnormal bony alignment. Cadaver specimen 4R had the one largest measured Q angles. In addition, it had the largest angle FPA in the study, resulting in a large lateral angulation of the femur and quadriceps femoris muscle. It appeared that this individual had adapted to this lateral malalignment with hypertrophy of the VMO. Component 1 had more than twice the average mass measured in our study (Tab. 1). Although the specimen had a relatively large Q angle, it was the only specimen in the study that had a quadriceps femoris muscle vector medial to the femoral shaft.

Individuals with abnormal lateral bony alignment may, therefore, necessitate overdevelopment of the VMO as a compensation. This overdevelopment may be facilitated by exercise intervention, which is currently the goal of many rehabilitation programs. We believe, however, that general quadriceps femoris muscle strengthening is contraindicated because it magnifies an already slightly laterally directed resultant force and must result in an increased lateral force on the patella. Our study

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**Figure 6.** Comparison of the Q angle measured with a standard clinical method (angle APT') with the Q angle measured using the quadriceps femoris muscle's resultant force as the proximal landmark (angle VPT'). (A=anterior superior iliac spine, P=center of patella, T=tibial tuberosity, T'=point of proximal extension of line PT, F=center of proximal femoral shaft, V=reference point for the direction of the quadriceps femoris muscle's resultant force in the frontal plane).
Table 1. Each Component's Average Fiber Length, Mass, Pennation Angle, and Deviation From the Femur (Standard Deviations Shown in Parentheses)

<table>
<thead>
<tr>
<th>Component</th>
<th>Fiber Length (cm)</th>
<th>Mass (g)</th>
<th>Pennation Angle</th>
<th>Component's Deviation From the Femur (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.6 (0.5)</td>
<td>71.3 (32.9)</td>
<td>0.0 (0.0)</td>
<td>48.1 (4.6) medial</td>
</tr>
<tr>
<td>2</td>
<td>7.2 (0.6)</td>
<td>93.0 (14.6)</td>
<td>0.0 (0.0)</td>
<td>37.3 (7.8) medial</td>
</tr>
<tr>
<td>3</td>
<td>7.1 (0.7)</td>
<td>154.7 (42.0)</td>
<td>19.4 (3.6)</td>
<td>4.1 (2.0) medial</td>
</tr>
<tr>
<td>4</td>
<td>6.7 (0.4)</td>
<td>134.4 (19.7)</td>
<td>6.0 (2.2)</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>5</td>
<td>7.0 (0.6)</td>
<td>185.2 (36.0)</td>
<td>15.2 (3.9)</td>
<td>2.4 (2.5) lateral</td>
</tr>
<tr>
<td>6</td>
<td>6.0 (0.6)</td>
<td>143.9 (34.9)</td>
<td>12.8 (3.9)</td>
<td>21.3 (2.0) lateral</td>
</tr>
<tr>
<td>7</td>
<td>6.0 (0.6)</td>
<td>201.7 (45.5)</td>
<td>14.5 (1.9)</td>
<td>27.6 (3.4) lateral</td>
</tr>
<tr>
<td>8</td>
<td>5.7 (0.8)</td>
<td>160.6 (35.0)</td>
<td>15.9 (3.1)</td>
<td>3.0 (1.3) medial</td>
</tr>
</tbody>
</table>

Table 2. Comparisons of Calculated and Measured Q Angles (Standard Deviations Shown in Parentheses)

<table>
<thead>
<tr>
<th>Cadaver</th>
<th>Calculated Q Angle (°)</th>
<th>Measured Q Angle (°)</th>
<th>Difference (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>18.4</td>
<td>14.0</td>
<td>+4.4</td>
</tr>
<tr>
<td>L1</td>
<td>20.8</td>
<td>15.0</td>
<td>+5.8</td>
</tr>
<tr>
<td>R2</td>
<td>23.7</td>
<td>19.0</td>
<td>+4.7</td>
</tr>
<tr>
<td>L2</td>
<td>17.8</td>
<td>15.0</td>
<td>+2.8</td>
</tr>
<tr>
<td>R3</td>
<td>21.6</td>
<td>20.0</td>
<td>+1.6</td>
</tr>
<tr>
<td>L3</td>
<td>15.3</td>
<td>11.0</td>
<td>+4.3</td>
</tr>
<tr>
<td>R4</td>
<td>23.8</td>
<td>20.0</td>
<td>+3.8</td>
</tr>
<tr>
<td>Average</td>
<td>20.2 (3.2)</td>
<td>16.3 (3.5)</td>
<td>+3.9 (1.4)*</td>
</tr>
</tbody>
</table>

*Significant (P = 0.003).

add support to the hypothesis that patellofemoral instability and pain in the majority of individuals is due to the lateral force on the patella secondary to the lateral alignment of the quadriceps femoris muscle's resultant force.2,5,7,9,14,20,24

Conclusion

We believe that the Q angle is a relevant clinical measurement. It should be noted, however, that the alignment of the quadriceps femoris musculature, which has a profound impact on patellar forces, is more laterally directed than the Q angle as measured by a standard clinical method would lead us to believe. It should be noted that all data were collected from male cadaver specimens. The results, therefore, may not be accurately generalized to females.

References