The Relationship of the Vector of Quadriceps function to the Femur
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Introduction:
Treatment of conditions around the human knee depends on understanding of the anatomy and biomechanics of the structures around the knee. An important part of the biomechanics is the structure and function of the quadriceps muscle. Thus, the quadriceps force vector or Q-angle is an important parameter for evaluating the knee kinematics. Three-dimensional imaging of the lower extremity makes it possible to construct a computer-based model of the quadriceps and to calculate the vector of pull of the muscle as its individual parts and as a whole.

The purpose of this study is to evaluate the three-dimensional force vector of the quadriceps femoris and to evaluate the relationship between the quadriceps vector and several anatomically derived axes.

Methods:
Computed tomography (CT) images of the thighs from hip to below the knee, taken from the radiology database of patients who had CT scans for reasons other than significant pathology at the knee were used. Scans were excluded if the patient was greater than 49 years old or had a history of major leg trauma, lower extremity pain of unknown origin, musculoskeletal surgery, or obvious deformity in lower extremities.

The CT scans were digitized and converted to three-dimensional (3D) muscle models of each of the quadriceps components (vastus medialis, vastus intermedius, vastus lateralis, and rectus femoris). The 3D bone models (femur and patella) were also made and set bony landmarks to construct a coordinate system. We constructed the coordinate system based on the geometric center axis (GCA) that is, a line connecting the centers of spheres representing the medial and lateral posterior femoral condyles. The femoral X-axis was defined by the GCA (positive laterally). The origin of the coordinate system was defined as the midpoint between the centers of these posterior condylar spheres. The femoral Z-axis was defined as being perpendicular to the X-axis and in a plane formed by the X-axis and a line connecting the femoral origin and the center of the femoral head (positive superiorly). The femoral Y-axis was defined as the cross product of the Z-axis and X-axis (positive anteriorly).

The 3D muscle models were analyzed by principal component analysis to establish a vector representing the longitudinal axis of the muscle. The volume of the muscle was used to estimate the force with which the muscle could contract. The vectors for the individual quadriceps muscles were combined to calculate the direction and magnitude of the vector representing the overall quadriceps pull with the origin of the vector at the center of the patella. This combined vector’s position at the level of the center of the femoral head was evaluated. The following parameters were determined: (1) The quadriceps pull vector’s position relative to the center of the femoral head (XY plane); and (2) The angle between the quadriceps vector and the several anatomic axes: 1) the femoral shaft axis (anatomical axis), 2) the mechanical axis, and 3) a new concept, the spherical axis, a line connecting center of the femoral head and center of the medial posterior femoral condyle. The angle was calculated in 3D space and the angle was then projected onto a coronal plane prepared by one of two methods. The first plane includes the GCA and center of the femoral head. The other includes the transepidondylar axis (TEA) and the center of the femoral head. (See Figure 1)

Fourteen cases were evaluated (5 female: 9 male), 7 cases were right, 7 cases were left. The mean age of the subjects was 39.1 years old.

Results:
The quadriceps pull vector’s passing point at the level of the center of the femoral head.

All subjects’ quadriceps vector positions at the level of the center of the femoral head were anterolateral part from the center of the femoral head. The mean quadriceps vector’s position at the level of the center of the femoral head (normalized to a 25mm femoral head radius) was 33.6 ± 6.0mm lateral (range, 22.6 mm lateral to 41.1 mm lateral) and 41.6 ± 9.0mm anterior (range, 27.6 mm anterior to 57.7 mm anterior) from the center of the femoral head. In addition, at the level of the femoral neck, all subjects’ quadriceps vectors positions were anterior to the femoral neck that were located between the femoral head and the greater trochanter.

The angle between the quadriceps vector and the several anatomic axes.

In 3-D space, the angles between the quadriceps vector and the femoral shaft axis (anatomical axis), the mechanical axis, and the spherical axis were 3.1° ± 1.4° (range, 0.8° to 5.6°), 3.4° ± 0.8° (range, 2.0° to 4.8°), and 2.3° ± 0.9° (range, 0.7° to 3.6°), respectively. The spherical axis showed a significantly smaller difference than the mechanical axis. There were no statistically significant differences between the spherical axis and the femoral shaft axis angles, but the spherical axis angle tended to be smaller than that of the femoral shaft axis.

When projected to the GCA based coronal plane, the angles between the quadriceps vector and the femoral shaft axis (anatomical axis), the mechanical axis, and the spherical axis were 2.8° ± 1.2° (range, 0.7° to 5.0°), 3.3° ± 0.8° (range, 2.0° to 4.8°), and 0.8° ± 0.7° (range, 0.0° to 2.1°), respectively. The spherical axis was less than 1 degree different from the quadriceps vector and the difference was significantly smaller than the other two axes. In the TEA based coronal plane, the angles between the quadriceps vector and the femoral shaft axis (anatomical axis), the mechanical axis, and the spherical axis were 3.2° ± 0.8° (range, 2.0° to 4.8°), and 0.8° ± 0.6° (range, 0.0° to 1.9°), respectively. The spherical axis was also less than 1 degree different from the quadriceps vector and the difference was significantly smaller than the other two axes.

Discussion:
The function of quadriceps femoris affects knee kinematics directly. Contraction of the quadriceps femoris moves the tibia around the flexion axis of the knee. Thus, the relationship between the quadriceps pull vector and flexion axis of the knee is important. If there is a specific relationship between the quadriceps pull vector and flexion axis, for example if the relationship were 90 degrees, replacing the femoral component relative to quadriceps pull vector would make kinematic sense.

In this study, the calculated quadriceps vector was lateral to the mechanical axis and medial to the anatomical axis. When projected to the coronal plane, the spherical axis was less than 1 degree different from the quadriceps vector. This finding may indicate that the valgus angle of replacing femoral component of a total knee should be smaller than the current standard and the spherical axis may be an important landmark for kinematically correct total knee alignment.

NEW
In this study, the calculated quadriceps vector was lateral to the mechanical axis and medial to the anatomical axis. This finding indicates that the valgus angle for placement of the femoral component in total knee arthroplasty should be smaller than current standard.

Figure 1

Three-dimensional model of the femur and quadriceps muscle components with individual vectors, combined vectors and anatomically derived axes.