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Axis Location of Tibial Rotation and Its Change With Flexion Angle

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The magnitude and location of the axis of tibial rotation were measured at 15° increments between 0° and 90° flexion using 24 normal anatomic knee specimens, and their changes with flexion angle were investigated. The magnitude of tibial rotation was small (8.3°) at 0° flexion, but increased rapidly as the flexion angle increased and reached a maximum rotation (31.7°) at 30° flexion. It then decreased again with additional flexion (24.8° at 90° flexion). The location of the axis was close to the tibial insertion of the anterior cruciate ligament at 0° flexion, gradually moving toward insertion of the posterior cruciate ligament (observed at 45° and 60° flexion), and then moved anteriorly again with additional flexion: the axis was approximately equidistant from the two cruciate insertions at 90° flexion. The results showed that a relatively large degree of tibial rotation was possible in a normal knee and that the location of the axis remained approximately in the area between the two cruciate ligament insertions throughout the range of flexion. However, the location of the axis changed with the flexion angle within this area according to the changes in direction and tension of the cruciate ligaments and the surrounding soft tissues.

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It generally is recognized that tibial axial rotation is, with flexion and extension, one of the important elements of physiologic knee function. Therefore, it is essential to clarify the mechanism of tibial rotation to understand physiologic knee function. Numerous studies have been done on tibial rotation,[1–13] but only a few have discussed the location of the axis.[1,3,10,12] Such previous studies have shown that the location of the axis of rotation is approximately at the center of the tibial plateau,[1,10,12] where the taut cruciate ligaments are attached. However, a clear and detailed study of the location and its change with knee flexion angle has not yet been published.

In this study, the magnitude and location of the axis of tibial rotation were measured at various knee flexion angles from 0° to 90° flexion using normal anatomic knee specimens, and their changes according to the changes in knee flexion angle were investigated in detail.

MATERIALS AND METHODS

Twenty-four fresh frozen anatomic knee specimens were used. Seventeen knees were from men and seven were from women with an average age of 51 years (range, 22–67 years). None of the joints chosen for this study had macroscopic osteoarthritis or injured ligaments or menisci. Joints that could not extend to 0° flexion were excluded. The skin was removed but the ligaments and capsules were kept intact. The other soft tissues were preserved as far as possible.

An apparatus was designed and constructed to apply a constant internal or external rotatory torque on the tibia of a human anatomic knee specimen and to measure the movement of the tibia caused by these torques in three dimensions using biplanar photography[6–8] (Fig 1). A constant internal or external rotatory torque (3.5 Nm) was applied to the anatomic knee specimen without constraining any movement except changes in the flexion angle (5-degrees of freedom) using the string, pulley, and weight system. No axial load was applied. The position of the tibia relative to the femur was measured in three dimensions using biplanar photography. From the data obtained, the magnitude of tibial rotation that occurred within internal and external rotatory torques of 3.5 Nm at a fixed flexion angle was analyzed at 15° increments between 0° and 90° flexion. The positions of the tibial plateau under internal and external rotatory torques of 3.5 Nm at the same angle of flexion were projected onto the same plane perpendicular to the long axis of the tibia at each flexion angle (Fig 2). The location of the axis of tibial rotation then was calculated from these two projections and mapped on the outline of the tibial plateau. This apparatus and procedure have been described in detail.[6,7]

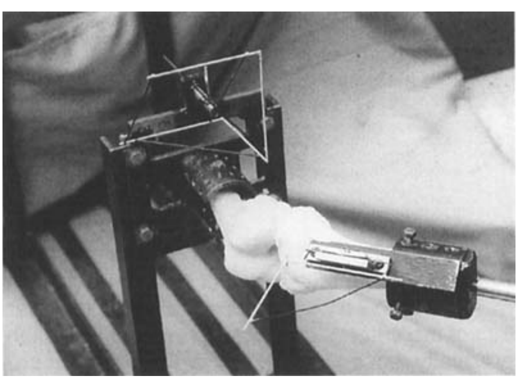

Fig 1. The apparatus designed and developed for this experiment. A constant internal or external rotatory torque (3.5 Nm) was applied to a human anatomic knee specimen using the string, pulley, and weight system. The position of the tibia relative to the femur then was measured in three–dimensions using biplanar photography.

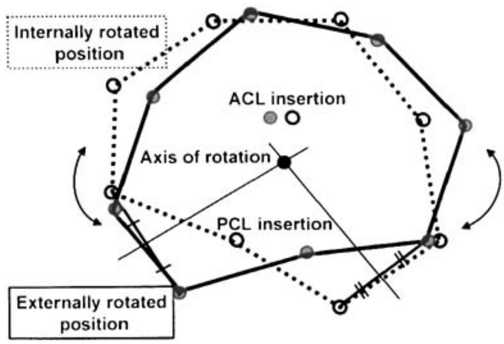

Fig 2. Calculation of the axis location. The positions of the tibial plateau under internal and external rotatory torques of 3.5 Nm at the same angle of flexion were projected onto the same plane perpendicular to the long axis of the tibia at each flexion angle, and the location of the axis of tibial rotation was calculated from these two projections. (ACL = anterior cruciate ligament; PCL = posterior cruciate ligament)

RESULTS

Magnitude of Tibial Rotation

The magnitude of tibial rotation that occurred within internal and external rotatory torques of 3.5 Nm changed with the knee flexion angle (Fig 3); on average, it was 8.3° at 0° flexion. This rapidly increased as the flexion angle increased, and the maximum rotation (31.7°) was observed at 30° flexion. It then decreased again as the flexion angle increased and was 23.9° at 75° flexion and 24.8° at 90° flexion.

Location of the Axis of Tibial Rotation

The data regarding the location of the axis initially were obtained in the form of a map of the axis on the tibial plateau at each flexion angle in each knee. The average value of the location could not be calculated directly from these

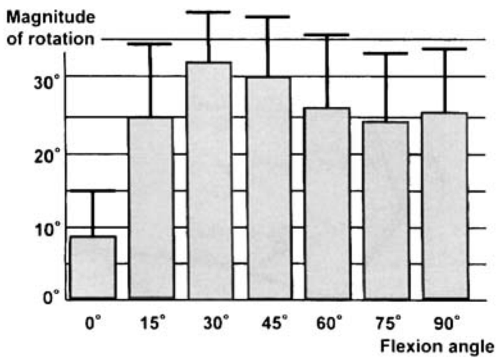

Fig 3. The magnitude of tibial rotation was relatively low (8.3°) at 0° flexion; this rapidly increased as the flexion angle increased, and the maximum rotation (31.7°) was observed at 30° flexion. It then decreased again as the flexion angle increased additionally (24.8° at 90° flexion).

data because the size and dimension of the tibial plateau differ from joint to joint. Therefore, the average value of the location was calculated by standardizing the positions of the tibial insertions of the anterior cruciate ligament and posterior cruciate ligament and the distance between the two.

On average, the location of the axis was approximately in the area between the tibial insertion of the anterior cruciate ligament and that of the posterior cruciate ligament throughout the range of flexion, but it changed within this area according to the flexion angle (Fig 4). In the anteroposterior (AP) direction, the location was slightly posterior to the tibial insertion of the anterior cruciate ligament at 0° flexion, gradually moved more posteriorly as the flexion angle increased, and was slightly posterior to the insertion of the posterior cruciate ligament at 45° and 60° flexion. The axis then moved anteriorly again with additional flexion and it was approximately equidistant from the two insertions of the anterior cruciate ligament and posterior cruciate ligament at 90° flexion. In the mediolateral direction, the location was approximately at the middle of the tibial plateau and only minimal movement was observed throughout the range of flexion.

In individual knees, although the location of the axis was slightly different in each joint (given with standard deviations in Fig 4), its movement according to change in the flexion angle was uniform. In the flexion range between 0° to 45° where the average values of the location moved posteriorly, the axis in individual joints moved posteriorly in 22 of the 24 joints (92%) in the flexion range from 0° to 15°, in all 24 joints (100%) in the flexion range from 15° to 30°, and in 20 joints (83%) in the flexion range from 30° to 45°. In the range between 60° and 90°, where the average value of the location moved anteriorly, the axis location in individual joints moved anteriorly in 20 of the 24 joints (83%) in the flexion range from 60° to 75°, and in 22 joints (92%) in the flexion range from 75° to 90°.

DISCUSSION

There are several factors that have an influence on the magnitude and the location of the axis of tibial rotation: (1) directions and ten-

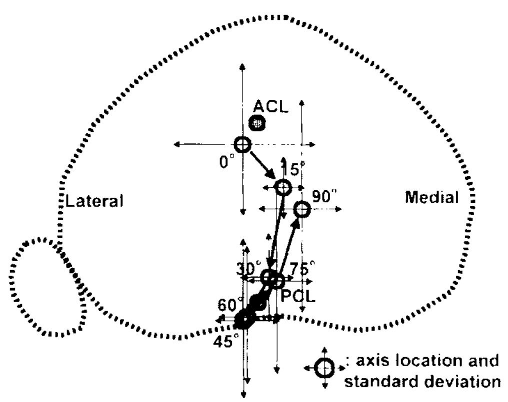

Fig 4. Location of the axis of tibial rotation. The location of the axis was close to the tibial insertion of the anterior cruciate ligament at 0° flexion, gradually moved toward that of the posterior cruciate ligament (observed at 45° and 60° flexion). The axis then moved anteriorly again with additional flexion and it was approximately equidistant from the two insertions of the anterior cruciate ligament and posterior cruciate ligament at 90° flexion. (ACL = tibial insertion of the anterior cruciate ligament, PCL = tibial insertion of the posterior cruciate ligament)

sions of the cruciate ligaments; (2) directions and tensions of the surrounding soft tissues including the medial collateral ligament, lateral collateral ligament and capsules; (3) the geometry of the femoral and tibial condyles; and (4) shape and movement of the menisci. These factors, however, may be changed according to change in the flexion angle, and the balances of these factors at each flexion angle have an influence on the magnitude and the location of the axis.

The magnitude of tibial rotation was small at 0° flexion and increased rapidly as the flexion angle increased, and reached maximum rotation at 30° flexion. These results are consistent with the findings in previous studies.[5,7,9] The surrounding soft tissues including the medial collateral ligament, lateral collateral ligament, and capsules are taut, and a large contact area between the femur and tibia was observed at 0° flexion, which might have caused the small magnitude of rotation in extension. On the contrary, the surrounding soft tissues were loose and the contact area between the femur and tibia were reduced in flexion, which might have allowed a substantial tibial rotation in flexion.

Only a few studies have been done examining the axis of tibial rotation. Shaw and Murray[10] investigated the location at 15° and 30° flexion using 11 human anatomic knee specimens and found that the axis was located around the medial intercondylar tubercle at both flexion angles. Trent et al[12] also measured the location using human anatomic knee specimens at angles ranging from hyperextension to 120° flexion and found that it was situated close to the center of the tibial plateau at all flexion angles, except at full extension where the axis was moved slightly toward the medial side. Brunet et al[1] investigated the locations at 0°, 30°, 60°, and 90° flexion using computed tomographic (CT) images of four anatomic knee specimens, and found that the axis was on the tibial spine at all flexion angles tested. According to the literature, the location of the axis of tibial rotation is approximately at the center of the tibial plateau. The results of the current study confirmed the above findings: the axis was located at approximately the center of the tibial plateau, in the area between the tibial insertion of the anterior cruciate ligament and that of the posterior cruciate ligament throughout the range of flexion.

However, a detailed analysis of the location of the axis revealed that it changed within this area according to changes in the angle of flexion. The location of the axis at 0° flexion was close to the tibial insertion of the anterior cruciate ligament, gradually moving toward that of the posterior cruciate ligament (observed at 45° and 60° flexion). Changes in tension of the cruciate ligaments (the anterior cruciate ligament is taut in extension and the posterior cruciate ligament taut in flexion) could have had an influence on the location of the axis. The anterior cruciate ligament is taut at 0° flexion, and tibial rotation occurs around this taut anterior cruciate ligament; the axis moved toward the posterior cruciate ligament when the knee is flexed, and in this range of flexion (between 45° and 60°) the anterior cruciate ligament becomes loose and the posterior cruciate ligament becomes taut.

The axis moved anteriorly again between 60° and 90° flexion and was equidistant from the two insertions of the anterior cruciate ligament and posterior cruciate ligament at 90° flexion. This movement of the axis cannot be explained by changes in direction and tension of the cruciate ligaments alone. It might have been caused by changes in tension along the surrounding soft tissues, particularly patellar tendon and anterior and posterior capsules. The cruciate ligaments and surrounding soft tissues are loose in flexion, but the patellar tendon and anterior capsule gradually become taut when the knee is brought from 60° to 90° flexion, which would cause the axis to be located more anteriorly from the posterior cruciate ligament insertion.

In this study, no axial load was applied, and therefore the magnitude and the location of the axis of tibial rotation might be determined mainly by directions and tensions of the cruciate ligaments and those of the surrounding soft tissues. The geometry of the femoral and tibial condyles and shape and movement of the menisci might have a larger influence on the magnitude and the location of the axis under a loading condition.

The authors conclude from this study that (1) The magnitude of tibial rotation was small at 0° flexion, rapidly increased with flexion, and then decreased again with additional flexion after maximum rotation at 30° flexion; (2) The location of the axis was close to the insertion of the anterior cruciate ligament at 0° flexion, gradually moving toward that of the posterior cruciate ligament (45° and 60° flexion), then moving anteriorly again with additional flexion; it was approximately equidistant from the insertions of the anterior cruciate ligament and posterior cruciate ligament at 90° flexion; and (3) Changes in direction and tension of the cruciate ligaments and of the surrounding soft tissues affected the movement of the location of the axis of tibial rotation.

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