Where
Is the Natural Internal-External Rotation Axis of the Tibia?

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Introduction: In an effort to improve implant survival and reduce complications with total knee arthroplasty (TKA), investigators have examined the proper alignment of the tibiofemoral components needed to restore normal kinematic function of the knee. A critical aspect to understanding proper alignment of the prosthetic components is determining the axes of rotation in the normal knee. In theory normal knee kinematics occur about two fixed axes [1, 2], a flexion-extension (F-E) rotation axis fixed in the femur and an internal-external (I-E) rotation axis fixed in the tibia. Clearly identifying these two axes will have implications not only on implant and prosthetic design, but in biomechanical testing and kinematic analyses as well. Both F-E and I-E rotations of the knee have previously been investigated using various methods [1-6], but controversy exists with regard to their definition, location, and orientation. In a parallel study we determined the natural F-E axis of rotation in the knee. This study sought to establish a consistent and reproducible natural I-E axis of tibial rotation. In addition, we examined possible left-right and male-female differences with respect to the axis orientation and location.

Methods: Fifteen fresh-frozen knees were used for this study (8 right, 7 left, 9 male, and 6 female). The mean age was 36 years. The femur and tibia of each specimen were sectioned 12 inches from the joint line and potted in polymethylmethacrylate. A custom built test apparatus was used in which the femur was secured and the tibia unconstrained, permitting flexion of the femur about the distal end of the femur free to translate and rotate. The fixture permitted positional adjustments of the femur such that flexion-extension of the femur occurred about the natural F-E axis of the knee. This was determined through a series of steps to minimize the motion at the distal end of the tibial plateau during 0-90° of passive flexion-extension of the femur. With the flexion axis established, each specimen was then subjected to a series of applied 2 Nm internal and external torques to determine the natural axis of tibial internal-external rotation.

Small markers were used to define the anterior, posterior, medial, and lateral margins of the tibia at three different levels: 1) On the tibial plateau, 5 mm distal to the articular cartilage margin at the greatest medial-lateral width and the greatest antero-posterior depth of the medial plateau. 2) Midway down the tibial shaft, 5 inches distal to the tibial plateau level. 3) At the distal end of the tibial shaft, 10 inches distal to the tibial plateau level. Throughout testing, the position and orientation of these markers were measured and recorded using a three-dimensional coordinate-measuring machine (CMM; Faro Gage, FARO Technologies Inc., Lake Mary, FL). With the distal end of the tibia unconstrained, the knee was positioned to 0°, 15°, 30°, and 45° of flexion. At each designated flexion angle, the markers were digitized using the CMM in the unloaded knee state, then with an applied 2 Nm external tibial torque followed by an applied 2 Nm internal tibial torque. Torque was applied to the tibia using a weight and pulley system 11 inches from the joint line that allowed the tibia to freely rotate. Tracking the change in position and orientation of the markers at these three different levels of the tibia enabled us to calculate a center of rotation at each level, and then determine the axis of I-E rotation from these three centers of rotation.

Center of rotation data was normalized to the medial-lateral width and antero-posterior depth of the tibial plateau. The center of the tibial plateau was defined where the midpoint between the anterior and posterior margins of the plateau intersected the midpoint between the medial and lateral margins of the plateau. Statistical analysis for right-left and male-female comparisons was performed using an independent t-test for axis location and orientation. The significance level was set at p < 0.05.

Results: Internal-External Tibial Axis Location: The natural I-E rotation axis of the tibia intersected the tibial plateau in the postero-stabilized compartment (Figure 1). The average center of rotation for the I-E axis at the tibial plateau level was located 2.2 ± 3.8 mm (mean ± SD) medially and 6.1 ± 3.9 mm posteriorly from the center of the tibial plateau. Right-left and male-female comparisons showed no significant differences in postero-medial location of the center of rotation at the tibial plateau (p > 0.06). Internal-External Tibial Axis Orientation: In the frontal plane the natural I-E tibial rotation axis was found to be at an angle of 1.6 ± 4.2° valgus from the perpendicular to the tibial plateau surface (Figure 2 A). Likewise, in the sagittal plane the natural I-E tibial rotation axis was extended at an angle of 5.6 ± 4.2° from the perpendicular to the tibial plateau surface (Figure 2 B). In the sagittal plane both right-left and male-female comparisons showed no significant differences in orientation of the I-E tibial rotation axis (p > 0.12). However, while there were no significant right-left differences in orientation of the I-E tibial rotation axis in the frontal plane (p > 0.93), there was a significantly different frontal plane orientation in male knees (-0.6 ± 3.9°) compared to female knees (4.9 ± 1.8°; p < 0.02).

Discussion: Our results show consistencies with prior work in that the center of I-E rotation of the natural knee I-E axis at the
tibial plateau is located posteromedially [1, 2], and its orientation is non-parallel to the perpendicular of the tibial plateau surface. Likewise, our results indicate that the natural I-E axis is not perpendicular to the transepicondylar axis of the femur, but oriented 2.8º valgus from its perpendicular. This is important as the transepicondylar axis is often used clinically to guide TKA alignment, thus consideration should be given to implant design and alignment. Having a clearly defined set of axes to describe knee joint kinematics will lead to further refinement of optimal alignment for replacement and prosthetic knee components. Knowing the natural kinematic axes of the knee will promote improved biomechanical testing and knee kinematic studies.

**Significance:** A defined natural I-E rotation axis of the knee will help optimize alignment for TKA components, improving implant survival while reducing associated TKA complications such as patellofemoral maltracking.

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**References:**
Figure 1. The mean axis of internal-external tibial rotation intersects the tibial plateau in the posterior-medial compartment, 2.2 mm medial and 6.1 mm posterior to the center of the tibial plateau (shown as mean ± SD). Each "x" indicates the I-E axis intersection of an individual specimen (n = 15).
Figure 2. The axis of tibial L-E rotation (red line; $n = 15$) relative to the
lateral and medial markers.

A. $1.6^\circ$ Valgus

B. $5.1^\circ$ Extension