The Flexion-Extension Axis of the Knee and the Rotational Orientation of Tibial Components

Introduction
Proper rotational alignment of the tibia with respect to the femur is a common source of instability and failure of total knee replacements. This has led to empirical guidelines for correct orientation of tibial components based on bony landmarks, including the tibial tubercle, the tibial spines and the site of insertion of the PCL. Some authors have even suggested orientation with respect to the foot. The potential weakness of all of these approaches is that they all ignore the femur, and they are based on static relationships, independent of the plane of motion of the knee. In this study, we examine differences between rotational axes based on anatomic landmarks and the true axis of knee motion during a functional activity.

Materials and Methods
24 fresh-frozen lower limb specimens were mounted in a computer-controlled 6dof activity simulator with application of loads simulating the physiologic contraction of the four heads of the quadriceps, the hamstrings and body weight. Each specimen was oriented and loaded to perform (i) a lunging maneuver, and (ii) a squatting maneuver. During these activities, the 3D positions and orientations of the femur, tibia, and patella were continuously monitored using a motion analysis system.

Computer models of the femur and tibia were reconstructed from CT scans and the orientation of the anatomic axes of the femur and the tibia were defined at 15-degree increments. The plane of best fit to the positions of the femur from 30-90 degrees was projected onto the proximal surface of the tibia. The resulting line of intersection was defined as the motion axis of each knee (TFA). The orientation of the TFA was compared to the following 5 different anatomic axes proposed for alignment of the tibial component:

1. Normal to the ML bisector of the tibial plateaus (MLA)
2. Normal the tangent to the posterior edge of the proximal tibia (PCA)
3. A line connecting the center of the tibial surface to the center of the tibial tubercle (MTA)
4. A line connecting the center of the tibial surface to the medial third of the tibial tubercle (TTA)
5. Normal to the femoral epicondylar axis measured with the knee in extension and projected onto the surface of the tibia (FEA)

Results
The deviation of the 5 different anatomic axes from the direction of knee flexion ranged from 1.2° ER to 14.2°IR depending on the activity and the axis. During squattting, the closest estimate of the axis of knee motion was provided by the axis joining the medial-third of the tibial tubercle to the center of the plateau which was externally rotated by 1.2°±5.0° (range: 19.4°). In the lunge maneuver, the trans-epicondylar axis of the femur (FEA) provided a more accurate estimate (ExtRot: 2.4±2.6°. For all axes except the trans-epicondylar axis, knee motion was 2.5°-3.6° more internally rotated during squatting compared to lunging (p<0.0010-0.0508). However, there the orientation of the TFA as virtually identical during both maneuvers (Lunge: -2.4±2.6°; Squat: -2.6±3.6°, p>0.05). The results are summarized in Table 1.

Conclusions
1. Rotational axes derived from anatomic landmarks on the tibia do not provide a reliable an estimate of the direction of knee motion during functional activities.
2. The relationship between knee motion the anatomic axes is different for squatting and lunging, and presumably other activities as well.
3. The trans-epicondylar axis of the femur is the most robust and least variable estimator of the direction of knee motion during functional flexion-extension maneuvers. However, individual variations of ±5-7° should still be anticipated.

Table 1. Data describing the deviation between each anatomic axis and the motion axis of the knees studied. Internal rotation is positive. The p value relates to the difference between squating and lunging values.

<table>
<thead>
<tr>
<th>Axis</th>
<th>Lunge Avg</th>
<th>Lunge StDev</th>
<th>Lunge Range</th>
<th>Squat Avg</th>
<th>Squat StDev</th>
<th>Squat Range</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLA</td>
<td>6.6</td>
<td>4.6</td>
<td>17.0</td>
<td>9.1</td>
<td>6.0</td>
<td>25.3</td>
<td>0.0508</td>
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<td>PCA</td>
<td>9.4</td>
<td>5.1</td>
<td>18.4</td>
<td>12.4</td>
<td>5.3</td>
<td>23.1</td>
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<td>TTA</td>
<td>-14.2</td>
<td>4.0</td>
<td>25.2</td>
<td>-11.4</td>
<td>2.9</td>
<td>19.1</td>
<td>0.0010</td>
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<tr>
<td>MTA</td>
<td>-4.8</td>
<td>4.0</td>
<td>15.1</td>
<td>-1.2</td>
<td>5.0</td>
<td>19.4</td>
<td>0.0015</td>
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<tr>
<td>FEA</td>
<td>-2.4</td>
<td>2.6</td>
<td>12.5</td>
<td>-2.6</td>
<td>3.6</td>
<td>16.0</td>
<td>0.7614</td>
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