Is There a Reference Line or Method That Sets the Rotation of the Tibial and Femoral Components Parallel to the Sagittal Kinematic Plane?

Alexander Nedopil¹, Abheetinder S. Brar², Joshua D. Roth², Stephen M. Howell²,³,⁵, Maximilian Rudert⁶, Maury L. Hull²,³,⁴

¹Department of Orthopedics; ²Biomedical Engineering Graduate Group; ³Department of Mechanical Engineering; ⁴Department of Biomedical Engineering, University of California, Davis, Davis, CA; ⁵Orthopedic Surgeon, Private Practice, Methodist Hospital, Sacramento, CA; ⁶Department of Orthopedic Surgery, University of Würzburg, König Ludwig Haus, Würzburg, Germany
This scientific exhibit presents the best method for setting internal-external (I-E) rotation of the tibial and femoral components in kinematically aligned total knee arthroplasty (TKA).

The introduction defines the sagittal kinematic plane and justifies setting the anteroposterior (AP) axis of the femoral and tibial components parallel to this plane. The first study shows that five tibial reference lines used in mechanically aligned TKA are not parallel to the sagittal kinematic plane. The second study shows that three femoral reference lines used in mechanically aligned TKA are not parallel to the sagittal kinematic plane. The final study shows a reliable surgical method for setting the rotation of each of the tibial and femoral components parallel to the sagittal kinematic plane.

The goal of this scientific exhibit is to encourage surgeons to use kinematic tibial and femoral reference lines when performing kinematically aligned TKA.

**Introduction**

TKA is a successful procedure for the majority of patients, however 20-25 percent of patients with a mechanically aligned TKA report dissatisfaction with their knee function. Correctly setting I-E rotation of the tibial and femoral components is one factor that affects function.

Setting component rotation is challenging because there is no consensus on the orientation of the ideal sagittal plane of the knee for establishing reference lines on the tibia and femur, and because finding these reference lines intraoperatively is unreliable.

In normal knee function, the tibia and patella flex and extend about two transverse axes perpendicular to the sagittal kinematic plane. If the goal is to restore natural knee function after TKA, then the ideal plane for setting the rotation of the tibial and femoral components is the sagittal kinematic plane.

**Kinematically Aligned TKA** is an alternative alignment method for which patient-reported satisfaction and function at 2 years is better and revisions at 3 years are fewer than mechanically aligned TKA. The goal for setting the rotation of each of the AP axis of the tibial and femoral components in kinematically aligned TKA is to set them parallel to the sagittal kinematic plane.

**Can Tibial Reference Lines Common to Mechanically Aligned TKA Be Used to Set Tibial Component Rotation in Kinematically Aligned TKA?**

Five tibial reference lines have been used in mechanically aligned TKA to set rotation of the tibial component. The present study determined whether any of these five tibial reference lines set the rotation of the tibial component parallel to the sagittal kinematic plane.
Scientific Exhibit 52, AAOS 2014   |    www.bme.ucdavis.edu/hull/

**Figure 4.** A composite of a right tibia shows the eight landmarks for constructing five tibial reference lines used in mechanically aligned TKA.

A. The most anterior point, medial border, and medial 1/3rd of the tibial tubercle (green arc), were identified on the projection of the tibia in the coronal kinematic plane.

B. The center of the PCL fossa and the center of the medial and lateral tibial condyles were identified on the axial kinematic plane of the proximal articular surface of the tibia.

C. The most posterior points on the medial and lateral condyles were identified 10 mm distal to the deepest portion of the medial tibial condyle, which shows the hollow cavity of the cortical bone. The yellow line is parallel to the sagittal kinematic plane.

**RESULTS**

Image analysis software (Paraview, Kitware Inc., www.paraview.org) was used to create a line parallel to the sagittal kinematic plane on the tibia in fifty three-dimensional (3-D) bone models of normal lower extremities from white subjects using a four-step alignment algorithm (Figure 3).

**METHODS AND MATERIALS**

**Figure 3.** The composite shows a 3-D model of a right lower extremity and the four steps for orienting the extremity in the three kinematic planes.

A. The bone model was imported into software.

B. The tibia was hidden, and the femur was projected in the sagittal kinematic plane by superimposing the medial and lateral femoral condyles.

C. The femur was projected in the coronal kinematic plane and perpendicular to the sagittal kinematic plane by placing the most posterior point of each femoral condyle and greater trochanter tangent to a surface.

D. The transformations applied to the femur were applied to the tibia, the tibia was projected perpendicular to the other two planes in the axial kinematic plane, and the line parallel to the sagittal kinematic plane (yellow) was drawn on the proximal articular surface of the tibia.

Eight landmarks were identified on each tibia (Figure 4 and Video).

Five tibial reference lines were drawn by connecting two landmarks and were termed (shown later in Figure 5 and Video):

1. Reference line connecting medial border of the tibial tubercle with the center of the PCL fossa.

2. Reference line connecting medial 1/3rd of the tibial tubercle with center of the PCL fossa.

3. Reference line connecting most anterior point of the tibial tubercle with center of the PCL fossa.

4. Reference line perpendicular to the line connecting the center of each tibial condyle.

5. Reference line perpendicular to the line connecting the most posterior point on each tibial condyle.

**Figure 4.** A composite of a right tibia shows the five tibial reference lines used in mechanically aligned TKA.

A. The most anterior point, medial border, and medial 1/3rd of the tibial tubercle (green arc), were identified on the projection of the tibia in the coronal kinematic plane.

B. The center of the PCL fossa and the center of the medial and lateral tibial condyles were identified on the axial kinematic plane of the proximal articular surface of the tibia.

C. The most posterior points on the medial and lateral condyles were identified 10 mm distal to the deepest portion of the medial tibial condyle, which shows the hollow cavity of the cortical bone. The yellow line is parallel to the sagittal kinematic plane.

The angle that each tibial reference line formed with the line parallel to the sagittal kinematic plane quantified the component rotation. A positive value indicated external rotation of that tibial reference line from the sagittal kinematic plane.

**Results**

The angle that each tibial reference line formed with the line parallel to the sagittal kinematic plane quantified the component rotation. A positive value indicated external rotation of that tibial reference line from the sagittal kinematic plane.

**Figure 5.** The composite shows the maximum external (positive) and internal (negative) rotation of each tibial reference line (orange) from the sagittal kinematic plane (yellow). Each tibia is viewed as right. The green arc outlines the tibial tubercle. The smallest range was 22°.
Our study shows that the five tibial reference lines common to mechanically aligned TKA externally rotate the tibial component from the sagittal kinematic plane. The surgeon can expect a wide range of component rotation when using a reference line that references the tibial tubercle because there is wide variability in the medial-lateral location of the tibial tubercle with respect to the medial border of the tibia. Accordingly, new methods that accurately set rotation of the tibial component in kinematically aligned TKA should be developed.

<table>
<thead>
<tr>
<th>Study</th>
<th>Can Femoral Reference Lines Common to Mechanically Aligned TKA Be Used to Set Femoral Component Rotation in Kinematically Aligned TKA?</th>
</tr>
</thead>
</table>

**BACKGROUND**

Three femoral reference lines have been used in mechanically aligned TKA to set rotation of the femoral component.

**PURPOSE**

The present study determined whether any of these three femoral reference lines set the rotation of the femoral component parallel to the sagittal kinematic plane.

**METHODS AND MATERIALS**

1. Image analysis software was used to create a line parallel to the sagittal kinematic plane on the femur in fifty 3-D bone models of normal lower extremities from white subjects using a four-step alignment algorithm (see previous Figure 3).
2. Six landmarks were identified on each femur (Figure 7 and Video).
3. Three femoral reference lines were drawn by connecting two landmarks (shown later in Figure 8 and Video) and were termed:
   1. The reference line parallel to the AP axis of the trochlear groove, which was defined as a line drawn through the deepest point on the trochlear groove and the center of the intercondylar notch.
   2. The reference line perpendicular to the transepicondylar axis, which was defined as a line drawn perpendicular to a line connecting the most prominent points on the femoral epicondyles.
   3. The reference line perpendicular to a line 3° externally rotated from the posterior condylar line, which was defined as a line perpendicular to a line 3° externally rotated from a line tangent to the posterior condyles.
4. The angle that each femoral reference line formed with the line parallel to the sagittal kinematic plane quantified the component rotation. A positive value indicated external rotation of that femoral reference line from the sagittal kinematic plane.
Our study shows that the three femoral reference lines common to mechanically aligned TKA externally rotate the femoral component from the sagittal kinematic plane. Because the posterior condylar line is perpendicular to the sagittal kinematic plane, it should be used to set the rotation of the femoral component in kinematically aligned TKA.
Seventy-one consecutive patients (71 knees) were treated from June to September 2012 with a kinematically aligned TKA performed with generic instruments as opposed to MRI-generated patient-specific instrumentation. A preoperative 1.5 T MRI scan was obtained of the knee in the sagittal kinematic plane. The femoral component with symmetric condyles was aligned parallel to the sagittal kinematic plane by adjusting the thickness of the posterior resections from the femur to equal that of the posterior regions of the condyles of the femoral component after compensating for wear and kerf. The tibial component was aligned parallel to the sagittal kinematic plane by aligning the AP axis of the trial tibial component parallel to the major axis of the nearly elliptical boundary of the lateral tibial condyle.

Figure 10. This composite shows the steps for kinematically aligning the femoral component.

A. A posterior referencing guide set in neutral rotation was positioned against the posterior femoral condyles.
B. The thickness of the posterior medial resection was measured with a caliper to the nearest 0.5 mm.
C. The thickness of the posterior lateral resection was measured with a caliper to the nearest 0.5 mm.
D. The thickness of each resection was verified to match the thickness of the posterior regions of the condyles of the femoral component after compensating for wear and kerf. This intraoperative check confirmed the AP axis of the femoral component was parallel to the sagittal kinematic plane.
The rotation of the femoral component from the sagittal kinematic plane did not correlate with the Oxford knee and WOMAC scores ($r = -0.17$ and $r = -0.10$, respectively). The Oxford knee score averaged $42 \pm 4.5$ and WOMAC score averaged $89 \pm 9.7$.

In vivo rotation of femoral component from sagittal kinematic plane

-1 Reference line parallel to the AP axis of trochlear groove
-2 Reference line perpendicular to transepicondylar axis
-3 Reference line parallel to a line 3° externally rotated from posterior condylar line

Femoral Reference Lines

Figure 13. On average, the rotation of the kinematically aligned femoral component was parallel to the sagittal kinematic plane (i.e. 95% confidence interval included 0), whereas the rotation of the three femoral reference lines common to mechanically aligned TKA was not. The femoral component rotation from the sagittal kinematic plane ranged from -3° to 2° (0.3° ± 1.1°). The rotation of the femoral component from the sagittal kinematic plane did not correlate with the Oxford knee and WOMAC scores ($r = -0.17$ and $r = -0.10$, respectively). The Oxford knee score averaged $42 \pm 4.5$ and WOMAC score averaged $89 \pm 9.7$. 

RESULTS

A thin slice (1.25 mm) CT scan of the knee was obtained after the TKA in these 71 patients.

At 6 months, patient-reported function was assessed with the Oxford knee score and WOMAC score. An Oxford knee score between 42 and 48 (best) indicates high function\(^5\). The 6-month Oxford knee score is of particular interest because it predicts the 10-year score, and the risk of revision within 2 years\(^5\).

The rotation of the femoral component and tibial component from the sagittal kinematic plane was computed from reference lines drawn on the MRI and CT scan (Figure 12 and Video).

A correlation coefficient was used to determine the strength of the relation between the rotation of the femoral component and tibial component from the sagittal kinematic plane and the Oxford knee and WOMAC scores at 6 months.

Figure 11. The composite shows the method for setting the AP axis of the tibial component parallel to the sagittal kinematic plane.

A. The approximately elliptical boundary of the lateral tibial condyle was outlined (black dots) and the major axis of the ellipse was drawn (blue line).

B. Two pins were drilled parallel to the major axis through the articular surface of the medial tibial condyle with a guide.

C. The tibial cut was made and two lines were drawn on the proximal tibia parallel to the two drill holes.

D. The AP axis of the trial tibial component was set parallel to these two lines.

Figure 12. The composite shows the method for measuring the I-E rotation of the AP axes of the femoral and tibial components from a line parallel to the sagittal kinematic plane.

A-D. On the MRI and CT scans, the femoral reference line connecting the medial and lateral epicondyles (A and B), and the tibial reference line tangent to the posterior tibia (C and D) were drawn and propagated across all slices.

E. On the MRI scan, a reference line was drawn perpendicular to the posterior condylar line to define the orientation of the sagittal kinematic plane.

F. On the CT scan, the femoral component reference line (green line) was drawn to connect the center of each lug on the femoral component. The AP axis of the femoral component (blue line) was drawn perpendicular to this reference line.

G. On the CT scan, the tibial component reference line (green line) was drawn tangent to the posterior border of the tibial component. The AP axis of the tibial component (blue line) was drawn perpendicular to this reference line.

The rotation of the AP axis of the femoral and tibial components from the sagittal kinematic plane was computed as the angle between each component reference line and the line parallel to the sagittal kinematic plane.
3. Adjusting the thickness of the posterior femoral resections equal to that of the posterior regions of the condyles of the femoral component after compensating for wear and kerf, and aligning the AP axis of the trial tibial component parallel to the major axis of the nearly elliptical boundary of the lateral tibial condyle achieve useful surgical techniques in kinematically aligned TKA.

The lack of correlation between the rotation of each of the femoral and tibial components from the sagittal kinematic plane and the Oxford knee and WOMAC scores, and the high average Oxford knee and WOMAC scores indicates that the range of rotation of the femoral and tibial component achieved with these two methods is compatible with high knee function.