SE 52

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

Alexander Nedopil[1], Abheetinder S. Brar[2], Joshua D. Roth[2], Stephen M. Howell[2,3,5], Maximilian Rudert[6], Maury L. Hull[2,3,4]

[1]Department of Orthopedics; [2]Biomedical Engineering Graduate Group; [3]Department of Mechanical Engineering; [4]Department of Biomedical Engineering, University of California, Davis, Davis, CA; [5]Orthopedic Surgeon, Private Practice, Methodist Hospital, Sacramento, CA; [6]Department of Orthopedic Surgery, University of Würzburg, König Ludwig Haus, Würzburg, Germany

SE 52

Overview of Scientific Exhibit

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

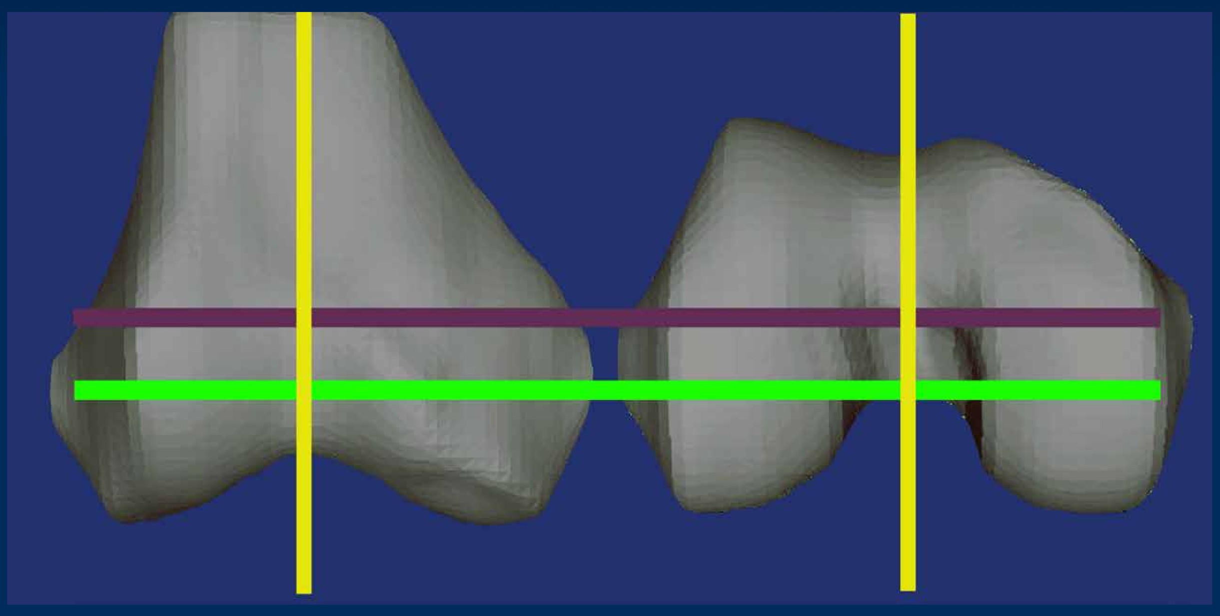

Figure 1. The composite shows a coronal and axial projection of the femur and the two parallel transverse axes in the femur that determine the flexion and extension path of the tibia (green line) and patella (magenta line). The two transverse axes are parallel to the distal and posterior joint lines and perpendicular to a line parallel to the sagittal kinematic plane (yellow line).

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[1, 2]. Correctly setting I-E rotation of the tibial and femoral components is one factor that affects function[3, 4].

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[3-5].

In normal knee function, the tibia and patella flex and extend about two transverse axes perpendicular to the sagittal kinematic plane (Figure 1)[6, 7]. 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[7-9].

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[10, 11]. 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 (Figure 2)[12].

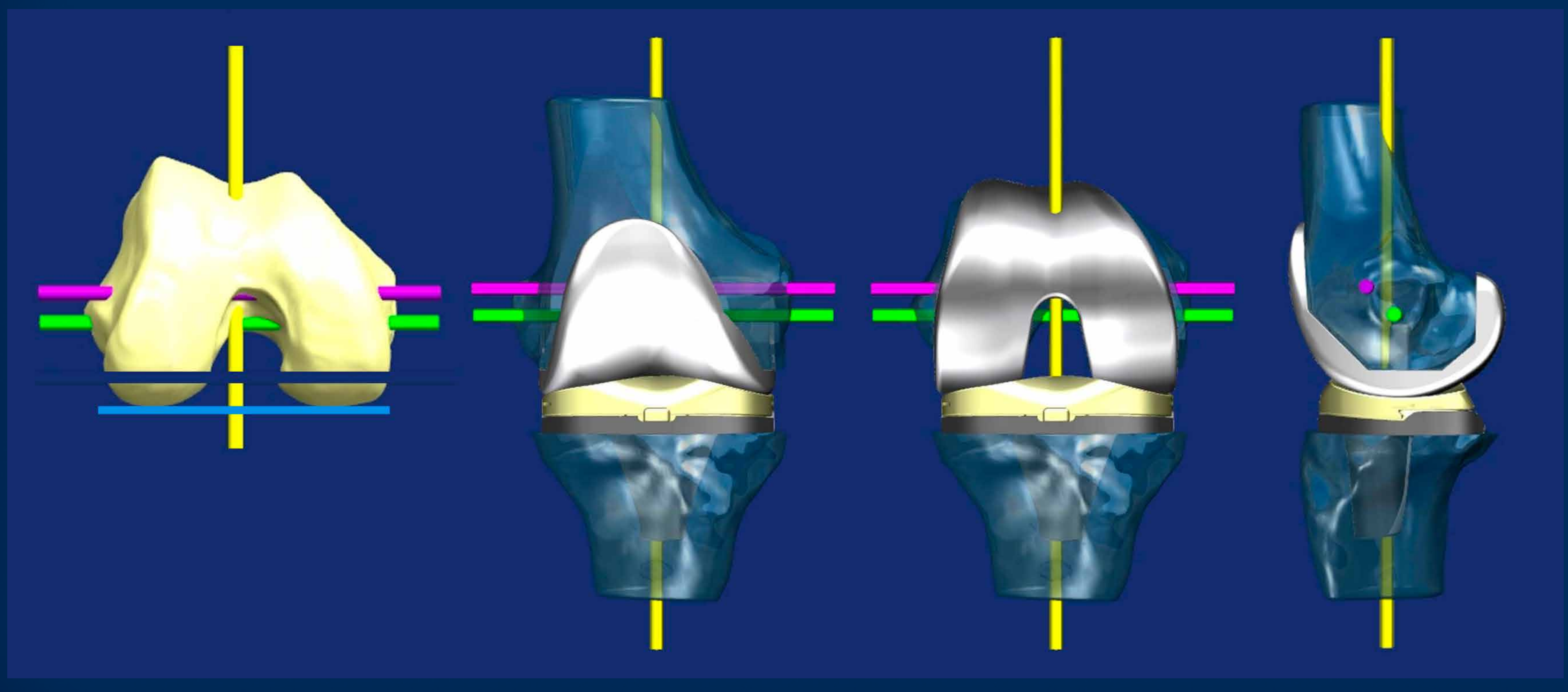

Figure 2. The sagittal kinematic plane (yellow line) is perpendicular to the posterior condylar line of the femur (blue line). The AP axis of the femoral component was drawn perpendicular to a line connecting the center of each lug on the femoral component. Adjusting the thickness of the posterior resections from the femur to equal that of the posterior regions of the condyles of the femoral component (after compensating for wear and saw blade kerf) aligns the AP axis of the femoral component parallel to the sagittal kinematic plane and restores the normal angle and level of the posterior joint line.

STUDY 1 Can Tibial Reference Lines Common to Mechanically Aligned TKA Be Used to Set Tibial Component Rotation in Kinematically Aligned TKA?

BACKGROUND

Five tibial reference lines have been used in mechanically aligned TKA to set rotation of the tibial component[3].

PURPOSE

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/

METHODS AND MATERIALS

1 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).

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

3 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.

4 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.

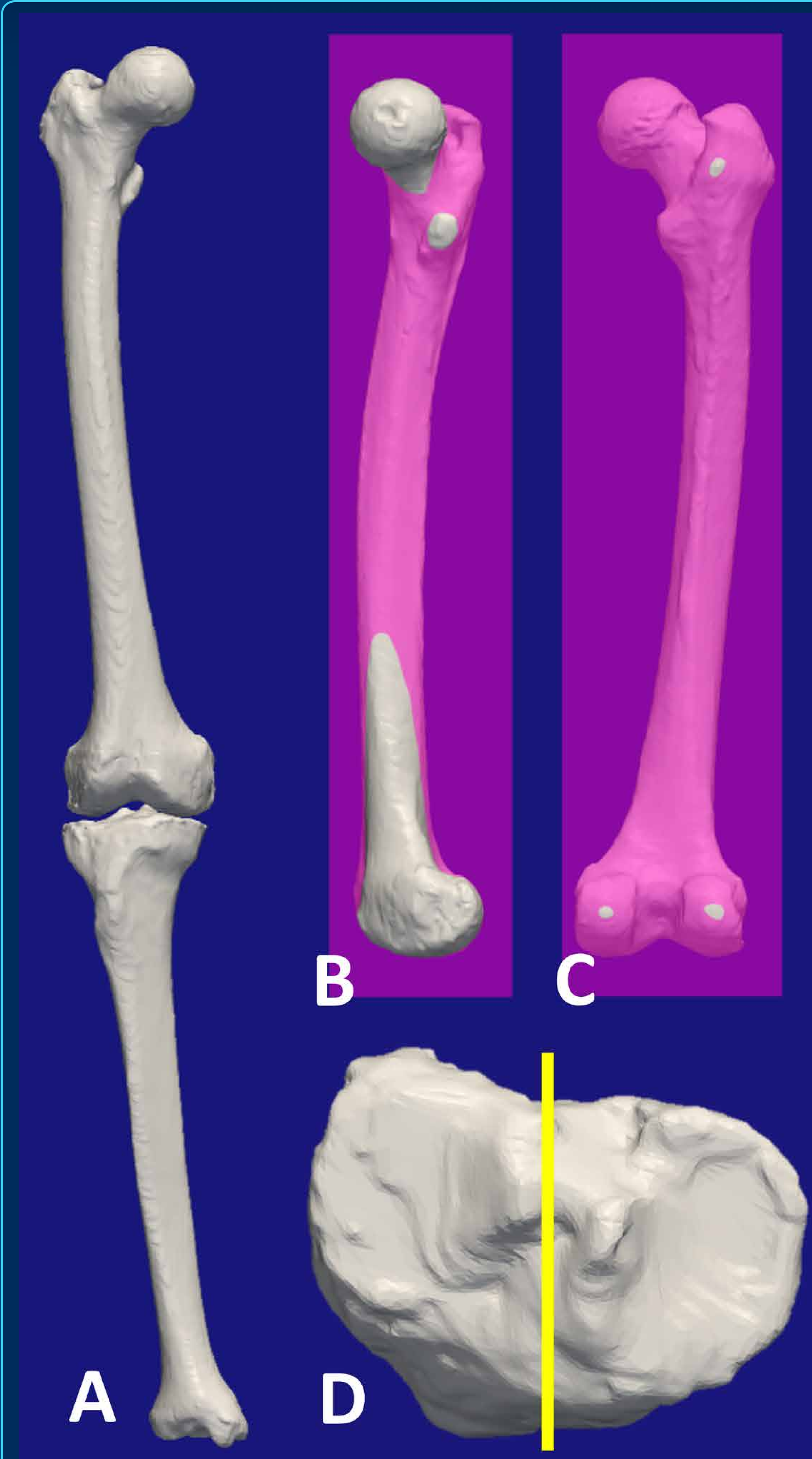

Figure 3. The composite shows a 3-D model of a right lower extremity and the four steps for orienting the extremity in the three kinematic planes.

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.

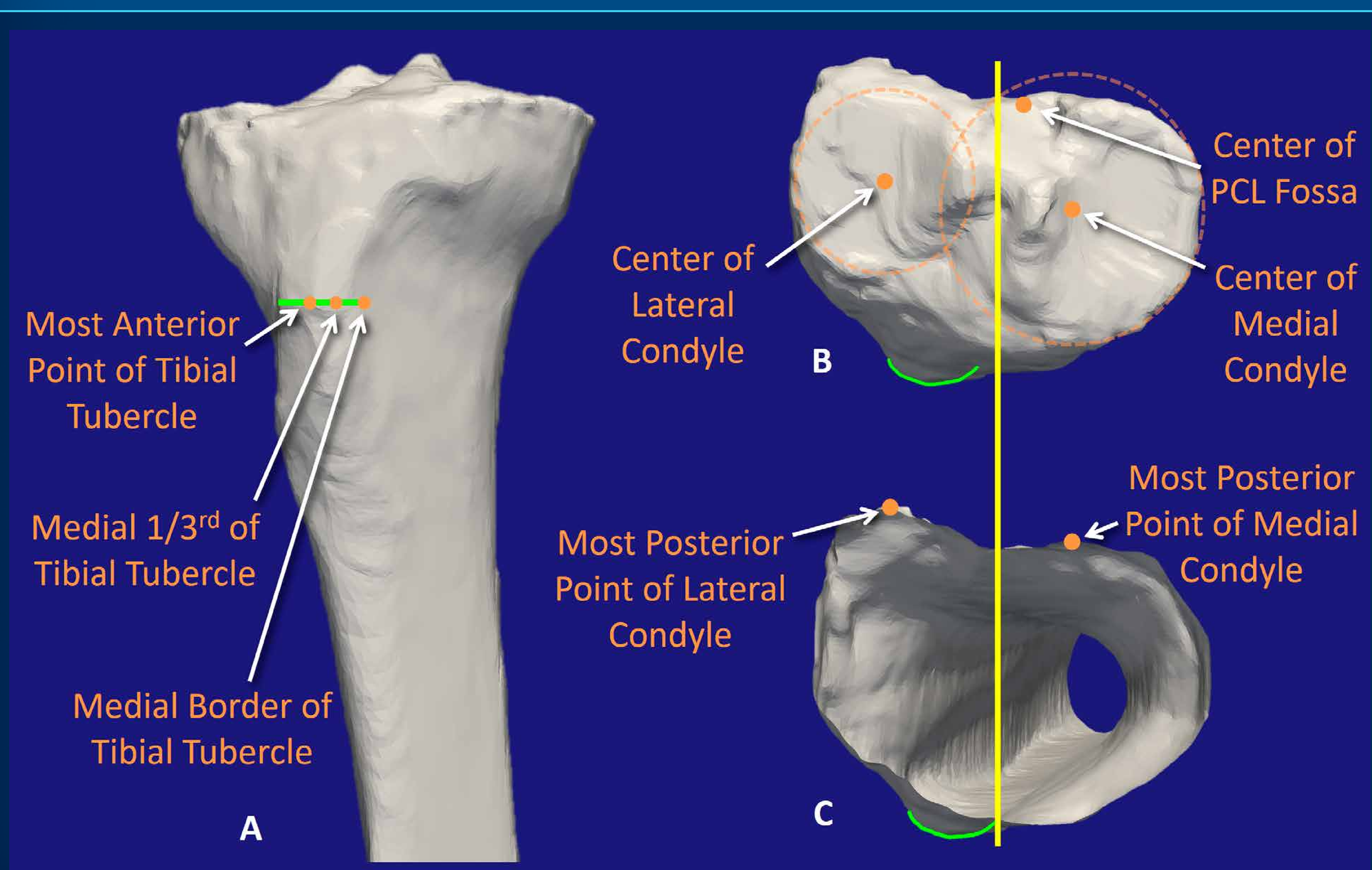

Figure 4. A composite of a right tibia shows the eight landmarks for constructing five tibial reference lines used in mechanically aligned TKA.

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

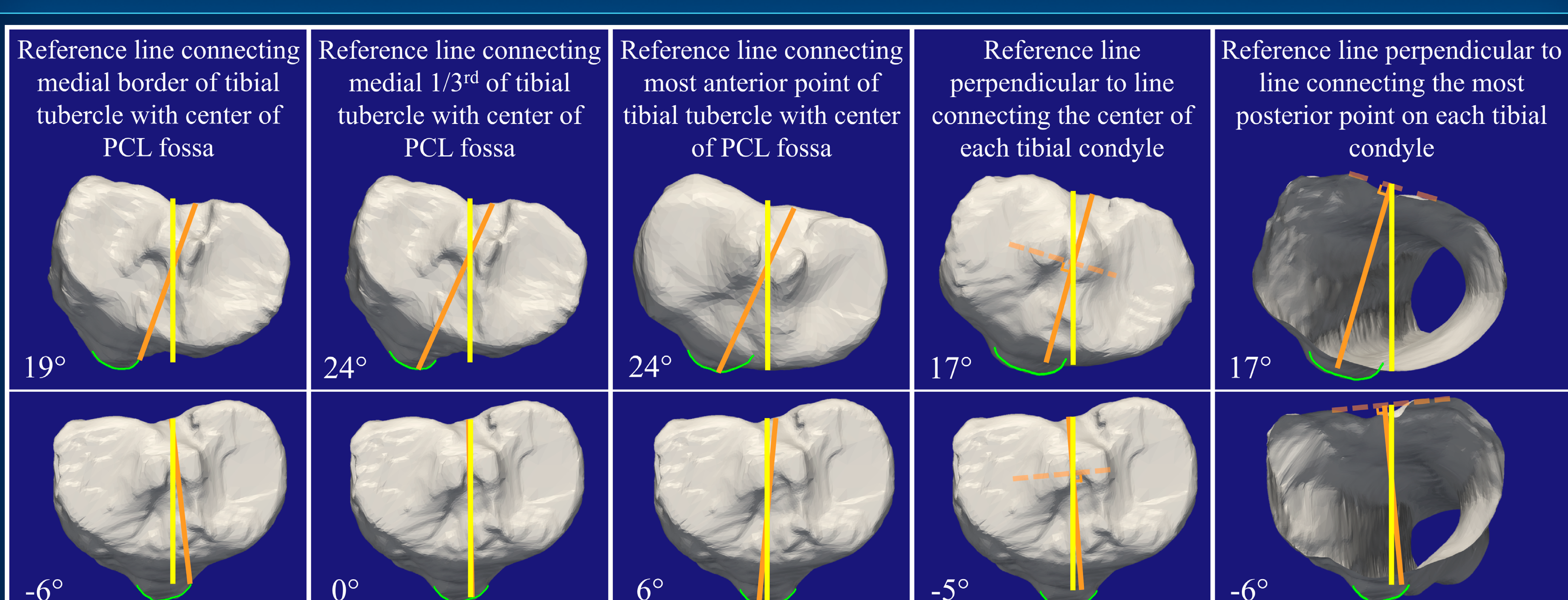

Figure 5. The composite shows the maximum external (positive) and internal (negative) rotation of each tibial reference line (orange) from the sagittal kinematic plane (yellow). Each tibia is viewed as right. The green arc outlines the tibial tubercle. The smallest range was 22°.

Scientific Exhibit 52, AAOS 2014 | www.bme.ucdavis.edu/hull/

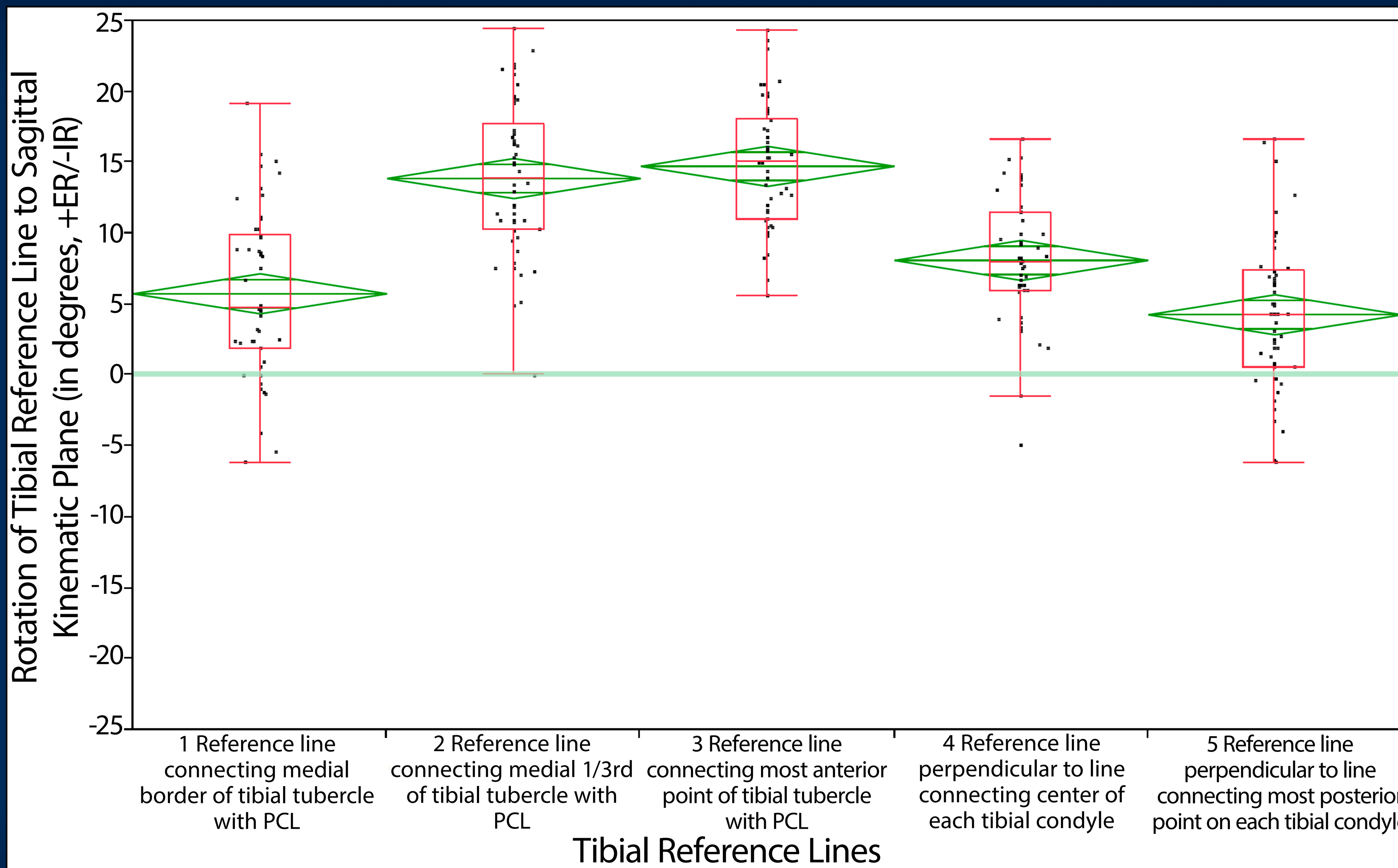

Figure 6. The graph shows the mean and the upper and lower 95% confidence limits (green diamond) of the rotation of each tibial reference line from the sagittal kinematic plane. The average rotation of each tibial reference line ranged from 4° to 15° external to the sagittal kinematic plane. The 95% confidence interval for all 5 tibial reference lines did not include 0 degrees. On average none of the five tibial reference lines were parallel to the sagittal kinematic plane.

DISCUSSION

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[13]. Accordingly, new methods that accurately set rotation of the tibial component in kinematically aligned TKA should be developed.

STUDY 2 Can Femoral Reference Lines Common to Mechanically Aligned TKA Be Used to Set Femoral Component Rotation in Kinematically Aligned TKA?

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.

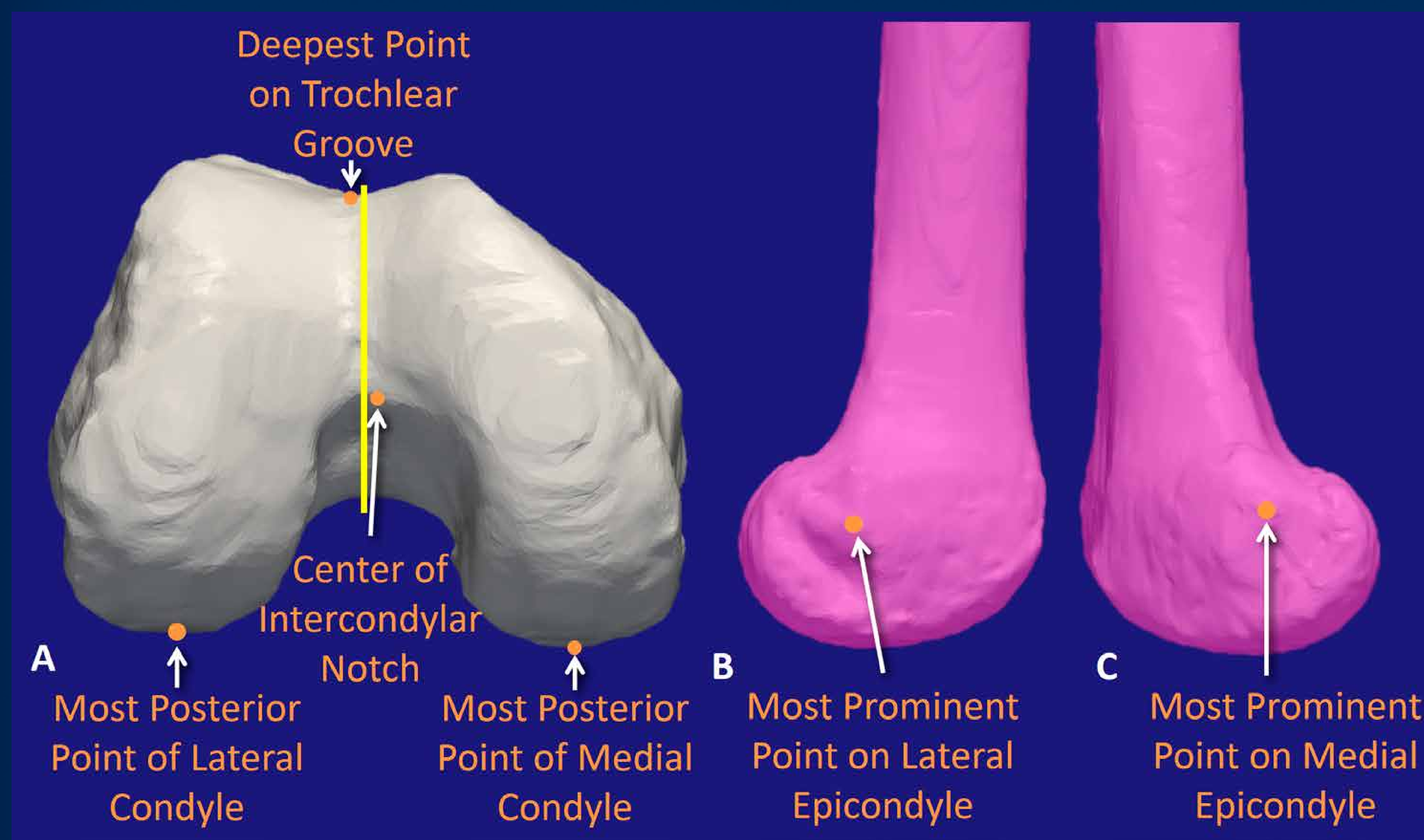

Figure 7. A composite of a right femur shows the six landmarks for constructing three femoral reference lines used in mechanically aligned TKA.

A. The deepest point on the trochlear groove, the center of the intercondylar notch, and the most posterior point on each of the lateral and medial femoral condyles were identified on the projection of the femur in the axial kinematic plane.

B. The yellow line is parallel to the sagittal kinematic plane. The most prominent point on the lateral epicondyle was identified on the lateral projection of the femur in the sagittal kinematic plane.

C. The most prominent point on the medial epicondyle was identified on the medial projection of the femur in the sagittal kinematic plane.

RESULTS

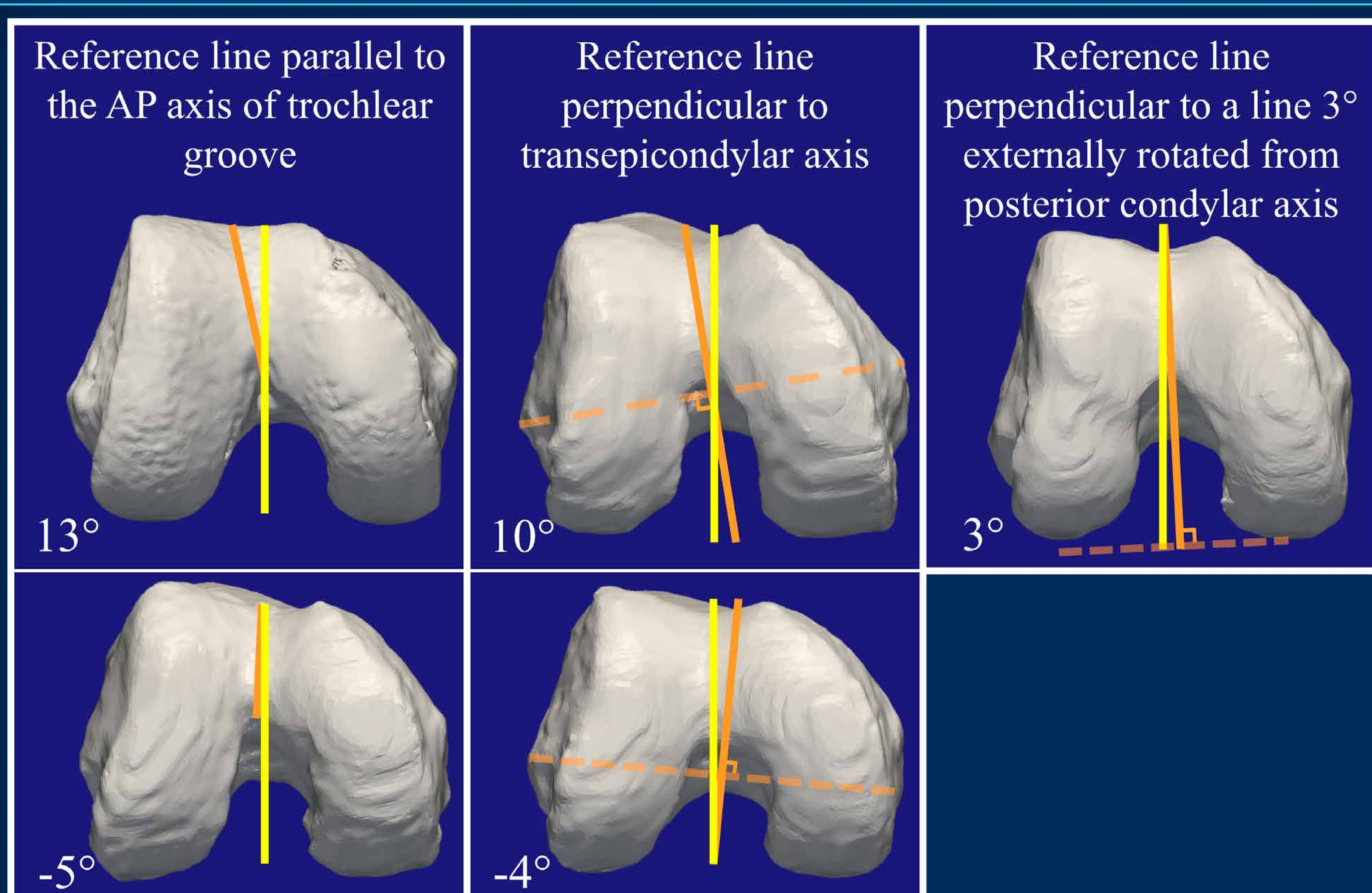

Figure 8. The composite shows the maximum external (positive) and internal (negative) rotation of each femoral reference line (orange), from the sagittal kinematic plane (yellow). Each femur is viewed as right. Each femoral reference line varied 3° or more from the sagittal kinematic plane. Specifically, the reference line parallel to the AP axis of the trochlear groove and the reference line perpendicular to the transepicondylar axis varied 14° and 18° respectively from the sagittal kinematic plane.

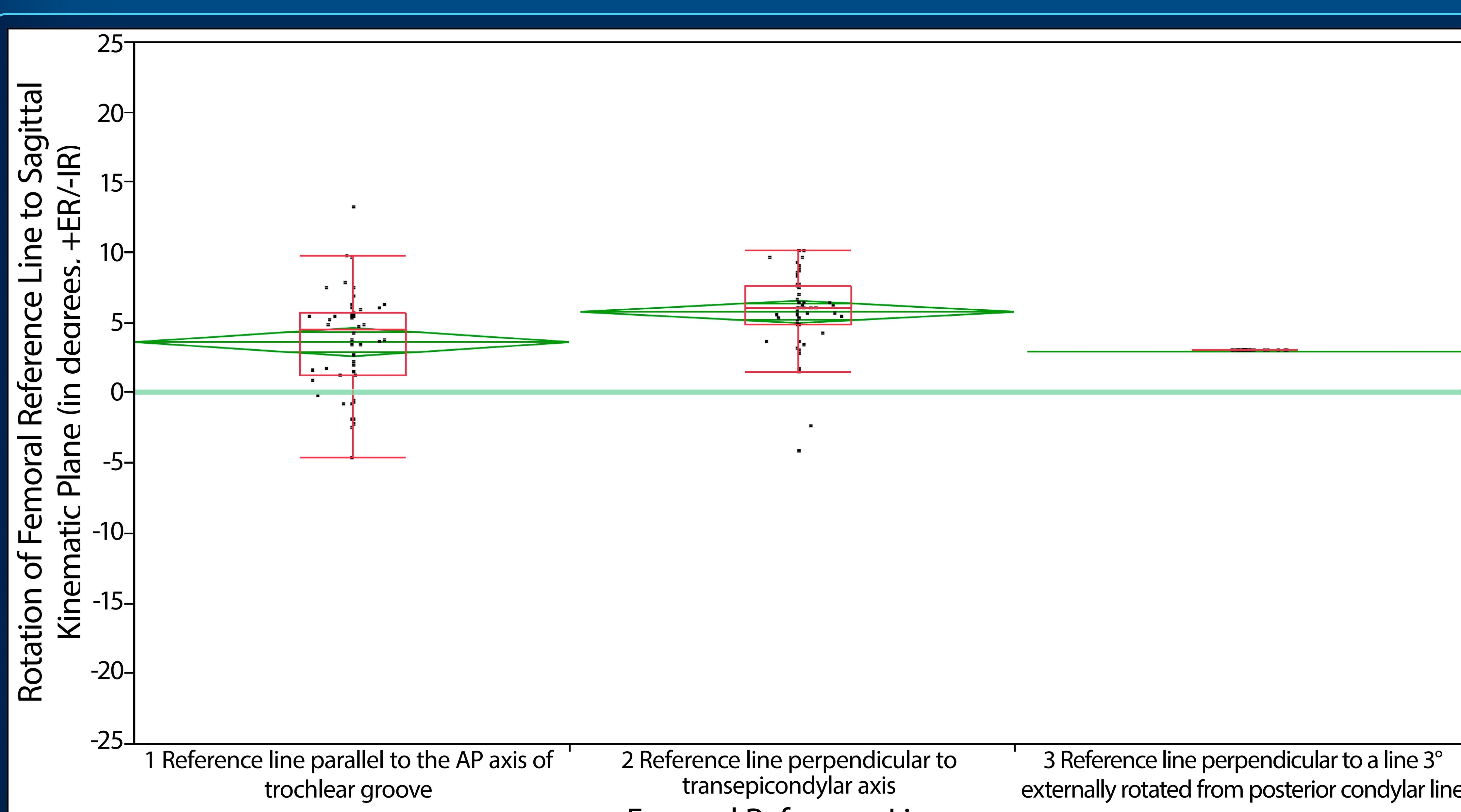

Figure 9. The graph shows the mean and the upper and lower 95% confidence limits (green diamond) of the rotation of each femoral reference line from the sagittal kinematic plane. The average rotation of each tibial reference line ranged from 3° to 6° external to the sagittal kinematic plane and all three femoral reference lines lacked a 95% confidence interval that included 0°. On average none of the three femoral reference lines were parallel to the sagittal kinematic plane.

DISCUSSION

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.

STUDY 3

Do Methods for Setting Component Rotation in Kinematically Aligned Total Knee Arthroplasty Achieve a Range of Rotation Compatible with High Function?

BACKGROUND

In kinematically aligned TKA, the method for setting the rotation of the femoral component is to adjust the thickness of the posterior femoral resections so they equal that of the posterior regions of the condyles of the femoral component after compensating for wear and kerf (see previous Figure 2). The method for setting the rotation of the tibial component is to align the AP axis of the trial tibial component parallel to the major axis of the nearly elliptical boundary of the lateral tibial condyle.

PURPOSE

The present study determined whether these two methods reliably set the rotation of the femoral and tibial components parallel to the sagittal kinematic plane in a case-series of patients treated with kinematically aligned TKA, and then determined whether the range of rotation achieved with these methods is compatible with high function.

METHODS AND MATERIALS

1. 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[10].
2. A preoperative 1.5 T MRI scan was obtained of the knee in the sagittal kinematic plane[11].
3. 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 (Figure 10).
4. 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 11)[10].

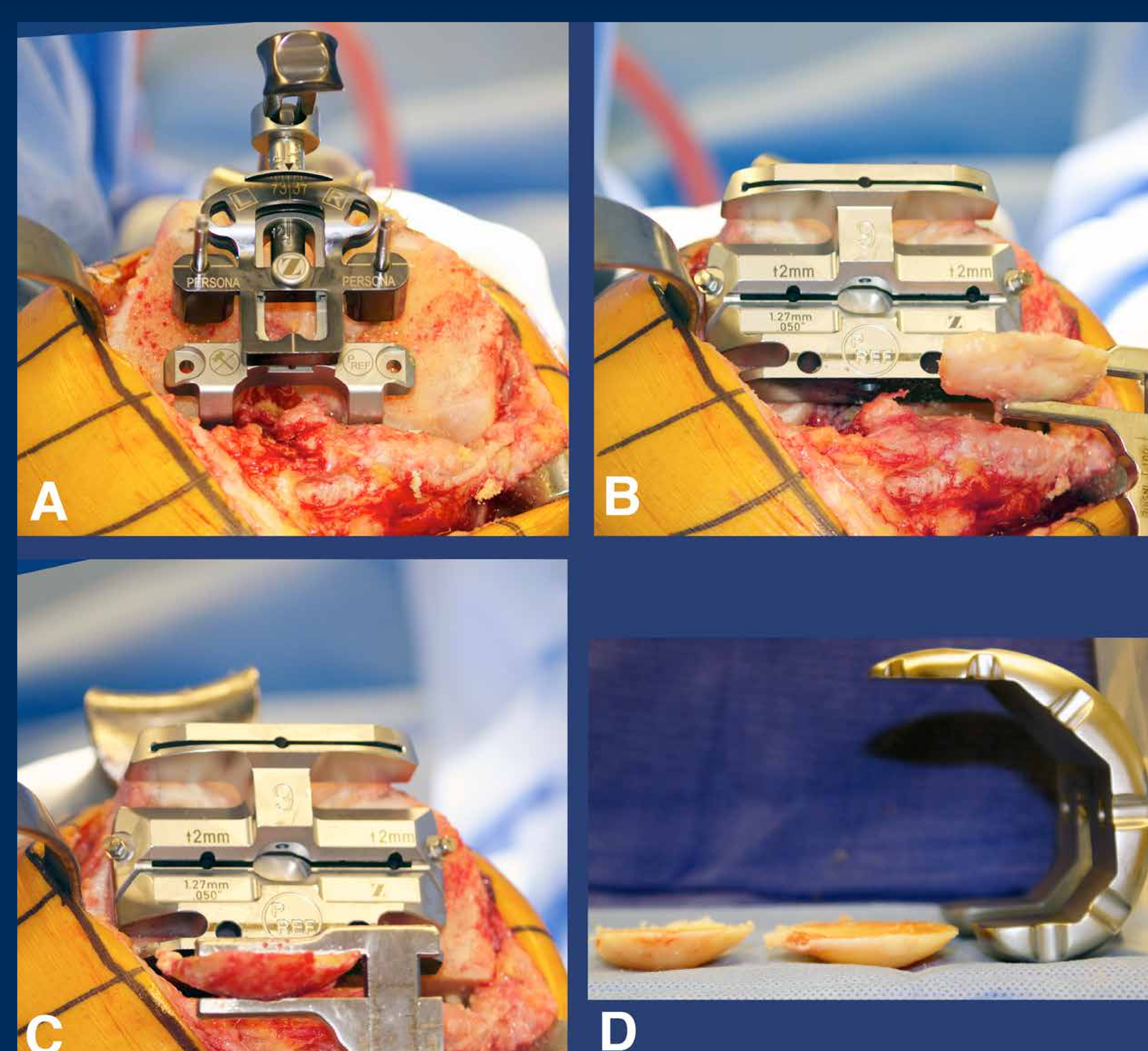

Figure 10. This composite shows the steps for kinematically aligning the femoral component.

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.

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

6 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[15]. 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[15].

7 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).

8 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.

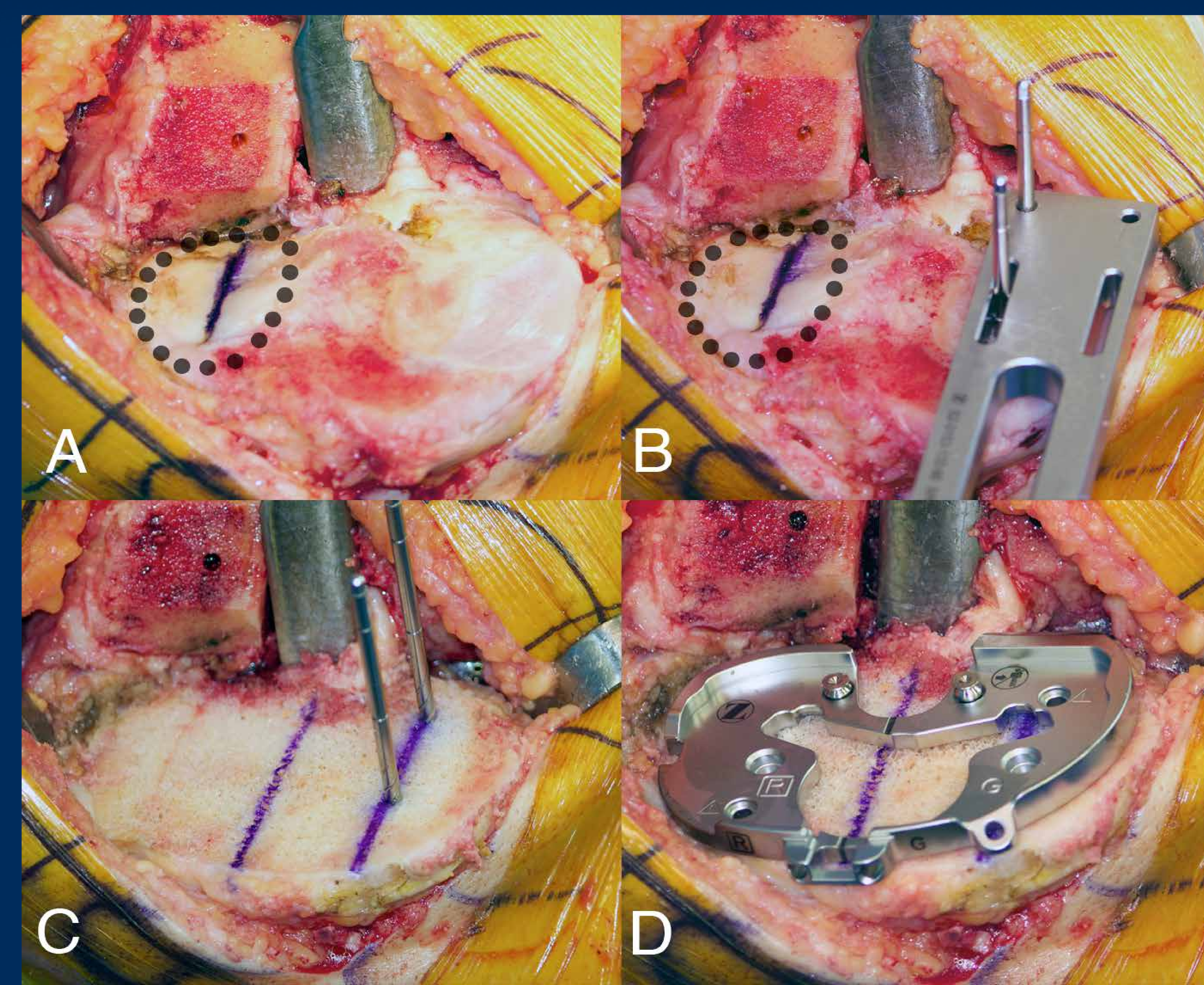

Figure 11. The composite shows the method for setting the AP axis of the tibial component parallel to the sagittal kinematic plane.

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.

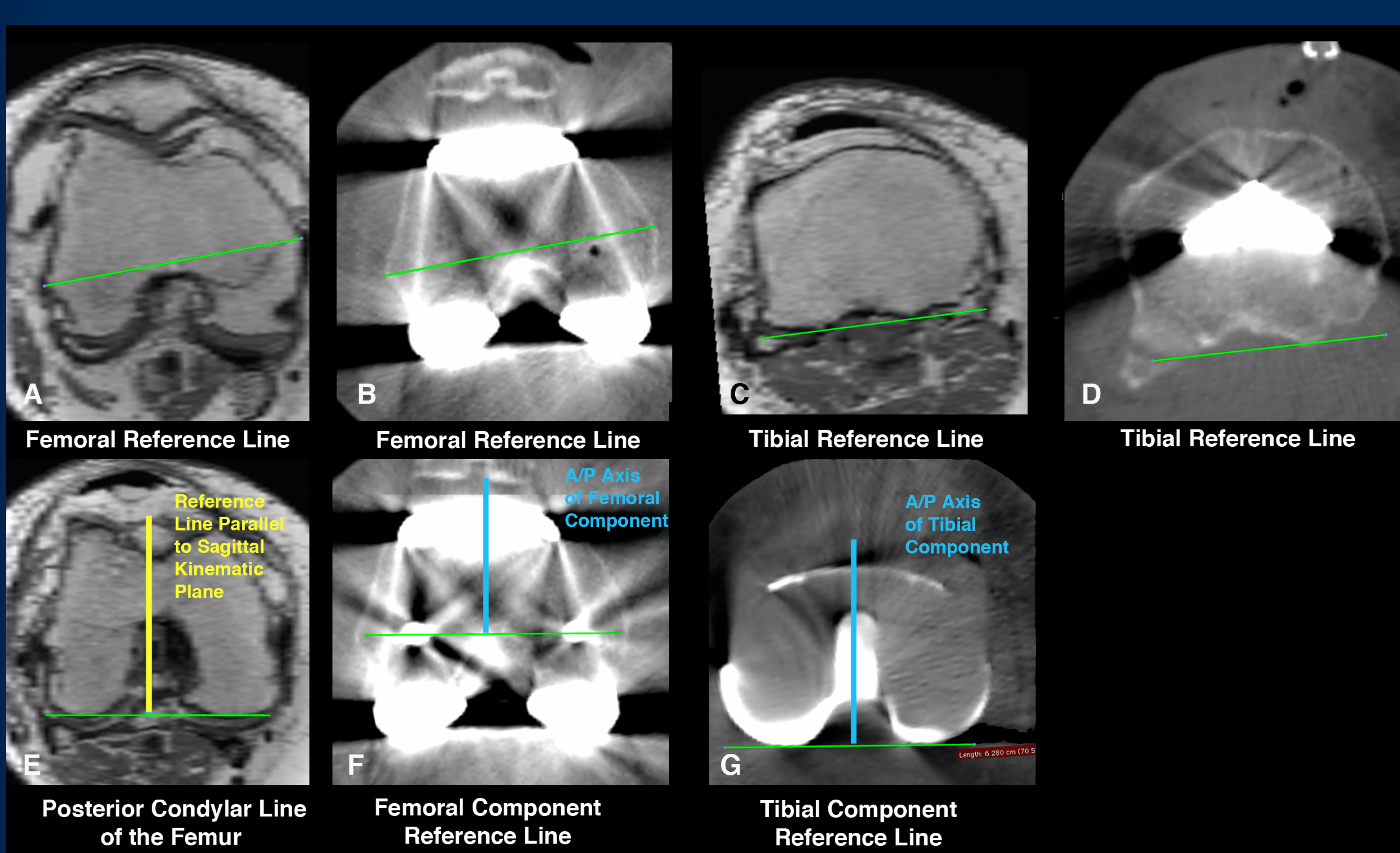

Figure 12. The composite shows the method for measuring the I-E rotation of the AP axes of the femoral and tibial components from a line parallel to the sagittal kinematic plane.

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.

RESULTS

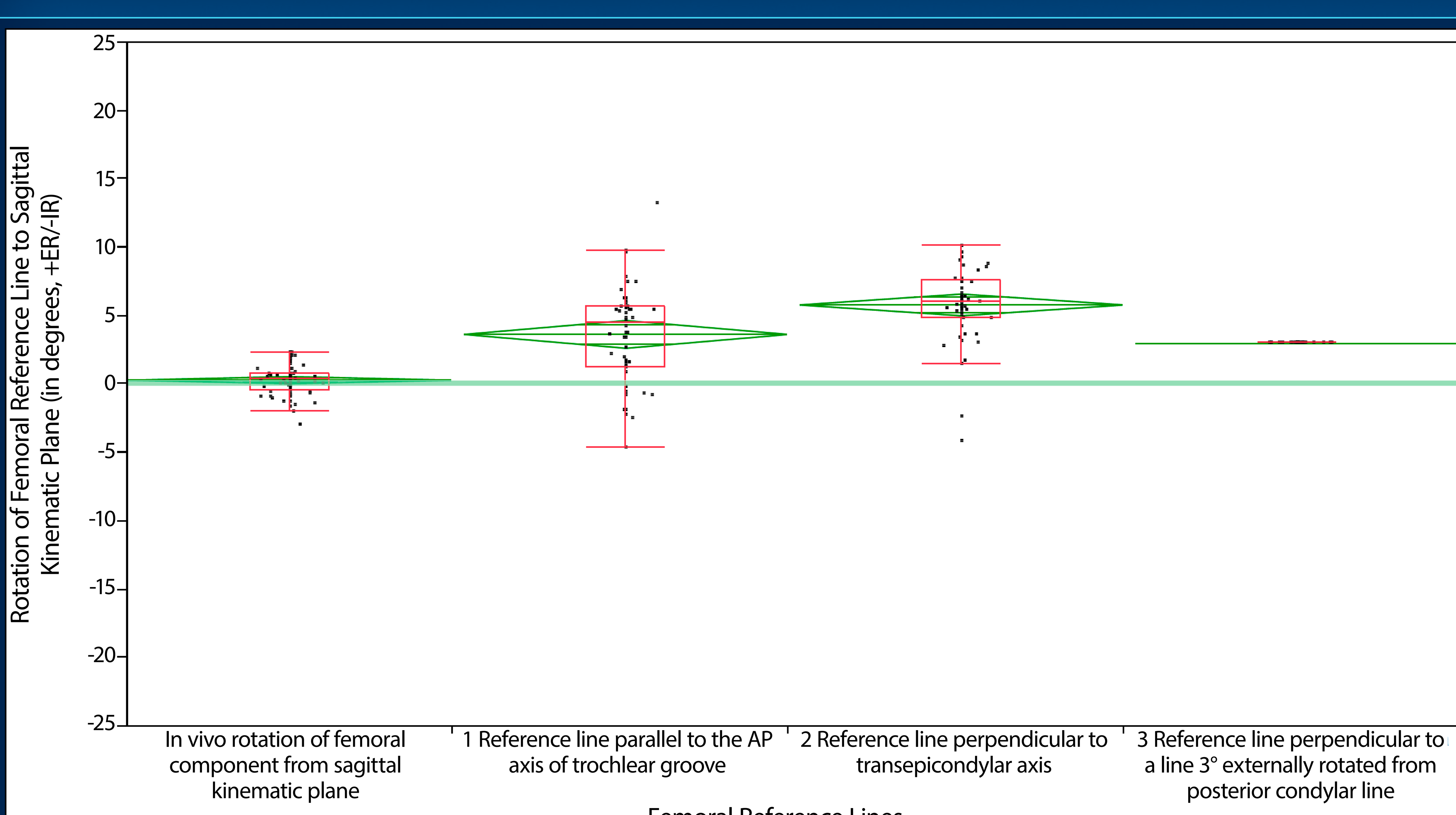

Figure 13. On average, the rotation of the kinematically aligned femoral component was parallel to the sagittal kinematic plane (i.e. 95% confidence interval included 0), whereas the rotation of the three femoral reference lines common to mechanically aligned TKA was not. The femoral component rotation 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 ± 4.5 and WOMAC score averaged 89 ± 9.7.

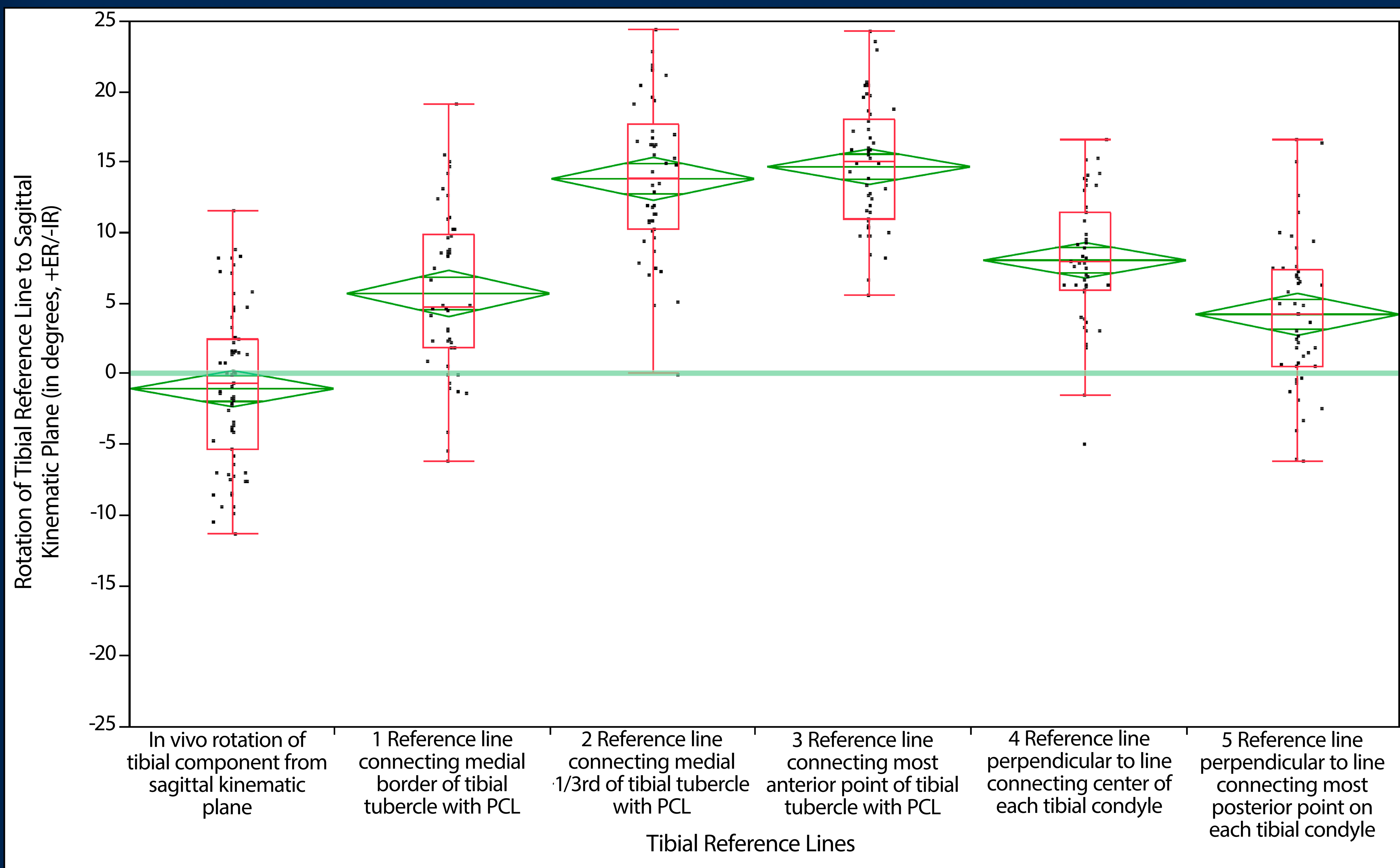

Figure 14. On average, the rotation of the kinematically aligned tibial component was parallel to the sagittal kinematic plane (i.e. 95% confidence interval included 0), whereas the rotation of each of the five tibial reference lines common to mechanically aligned TKA was not. The tibial component rotation ranged from -11° to 12° (-1.0° ± 5.4°).

The rotation of the tibial component from the sagittal kinematic plane did not correlate with the Oxford knee and WOMAC scores (r = - 0.16 and r = - 0.16, respectively).

DISCUSSION

The method of 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 the method of aligning the AP axis of the trial tibial component parallel to the major axis of the nearly elliptical boundary of the lateral tibial condyle are 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.

SE 52

Summary of Scientific Exhibit

Download materials using QR code

1. Mechanically aligned TKA uses a variety of tibial and femoral reference lines that, on average, externally rotate the tibial and femoral components from the sagittal kinematic plane. Hence, these lines are not optimal for use in kinematically aligned TKA.
2. The systematic external rotation of the components away from the sagittal kinematic plane may explain in part why patients with mechanically aligned TKA have lower satisfaction, function, and survivorship at 3 years, and more pain, rotational mismatch, and abnormal kinematics than patients with kinematically aligned TKA[10-12, 16, 17].
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 a range of rotation from the sagittal kinematic plane that is compatible with high function.

References

1. Baker PN, van der Meulen JH, Lewsey J, Gregg PJ, National Joint Registry for E, Wales: The role of pain and function in determining patient satisfaction after total knee replacement. Data from the National Joint Registry for England and Wales. J Bone Joint Surg Br 2007;89:893-900.
2. Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KDJ: Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clinical orthopaedics and related research 2010;468:57-63.
3. Siston RA, Goodman SB, Patel JJ, Delp SL, Giori NJ: The high variability of tibial rotational alignment in total knee arthroplasty. Clinical orthopaedics and related research 2006;452:65-69.
4. Siston RA, Patel JJ, Goodman SB, Delp SL, Giori NJ: The variability of femoral rotational alignment in total knee arthroplasty. The Journal of bone and joint surgery 2005;87:2276-2280.
5. Cobb JP, Dixon H, Dandachli W, Iranpour F: The anatomical tibial axis: reliable rotational orientation in knee replacement. J Bone Joint Surg Br 2008;90:1032-1038.
6. Coughlin KM, Incavo SJ, Churchill DL, Beynnon BD: Tibial axis and patellar position relative to the femoral epicondylar axis during squatting. The Journal of arthroplasty 2003;18:1048-1055.
7. Hollister AM, Jatana S, Singh AK, Sullivan WW, Lupichuk AG: The axes of rotation of the knee. Clinical orthopaedics and related research 1993;290:259-268.
8. Eckhoff D, Hogan C, DiMatteo L, Robinson M, Bach J: Difference between the epicondylar and cylindrical axis of the knee. Clinical orthopaedics and related research 2007;461:238-244.
9. Gu Y, Roth J, Howell SM, Hull ML: How frequently do four methods for mechanically-aligning a total knee arthroplasty cause collateral ligament imbalance and change alignment from normal in Caucasians? The Journal of bone and joint surgery In Press.
10. Dossett H, Swartz G, Estrada N, Lefevre G, Kwasman B: Kinematically versus mechanically aligned total knee arthroplasty. Orthopedics 2012;35:160-169.
11. Howell SM, Howell SJ, Kuznik KT, Cohen J, Hull ML: Does a kinematically aligned total knee arthroplasty restore function without failure regardless of alignment category? Clinical orthopaedics and related research 2012.
12. Nedopil A, Howell S, Rudert M, Roth J, Hull M: How Frequent is Rotational Mismatch Within 0 ± 10 degrees in Kinematically-Aligned TKA? . Orthopedics 2013;36:e1515-e1520.
13. Howell SM, Chen J, Hull ML: Variability of the location of the tibial tubercle affects the rotational alignment of the tibial component in kinematically aligned total knee arthroplasty. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2013;21:2288-2295.
14. Howell SM, Howell SJ, Hull ML: Assessment of the radii of the medial and lateral femoral condyles in varus and valgus knees with osteoarthritis. The Journal of bone and joint surgery 2010;92:98-104.
15. Listed NA: The New Zealand Joint Registry fourteen year report http://wwwnzoaorgnz/nz-joint-registry (date last accessed 16 November 2013).
16. Howell SM, Hodapp EE, Vernace JV, Hull ML, Meade TD: Are undesirable contact kinematics minimized after kinematically aligned total knee arthroplasty? An intersurgeon analysis of consecutive patients. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2013;21:2281-2287.
17. Nam D, Howell SM, Lombardi A, Berend M, Barrack R: The impact of patient specific cutting guides and mechanical and kinematic alignment on satisfaction and function after total knee arthroplasty. Clinical orthopaedics and related research Submitted.

Scientific Exhibit 52, AAOS 2014 | www.bme.ucdavis.edu/hull/