SE 46

Does Mechanical or Kinematic Alignment in Total Knee Arthroplasty Cause Collateral Ligament Instability and Change Limb and Knee Alignment from Normal?

Yu Gu[1], Joshua D. Roth[1], Stephen M. Howell[1,2,4], Maury L. Hull[1,2,3]

[1]Biomedical Engineering Graduate Group; [2]Department of Mechanical Engineering; [3]Department of Biomedical Engineering, University of California, Davis, Davis, CA; [4]Orthopedic Surgeon, Private Practice, Methodist Hospital, Sacramento, CA

OVERVIEW OF SCIENTIFIC EXHIBIT

PURPOSE

This scientific exhibit evaluates three alignment goals in total knee arthroplasty (TKA) with the purpose of determining the frequency that each alignment goal causes:

- A collateral ligament imbalance recognized as a tight collateral ligament at 0° of extension
- A collateral ligament imbalance recognized as an instability in a compartment between 0° of extension and 90° of flexion that is uncorrectable by collateral ligament release
- A change in limb and knee alignment from normal[1]

The first study shows that the goal of mechanically aligning the TKA with the limb set at a 0° hip-knee-ankle angle frequently causes both types of collateral ligament imbalance and changes knee and limb alignment from normal.

The second study shows that the goal of mechanically aligning the TKA with the knee set at 5° or 7° valgus frequently causes both types of collateral ligament imbalance and changes knee and limb alignment from normal.

The third study shows that the goal of kinematically aligning the TKA does not cause either type of collateral ligament imbalance and does not change limb and knee alignment from normal.

These results may explain why patients treated with a kinematically-aligned TKA report a higher rate of satisfaction, better function, and greater flexion than patients treated with mechanically-aligned TKA[2,3].

STUDY 1

How Frequently Do Four Methods for Mechanically Aligning a Total Knee Arthroplasty with the Limb Set at a 0° Hip-Knee-Ankle Angle Cause Collateral Ligament Imbalance and Change Alignment from Normal?

BACKGROUND

Surgeons mechanically align a TKA by setting the limb at a 0° hip-knee-ankle angle. Aligning the limb at 0° can create a collateral ligament imbalance recognized as 'a tight collateral ligament at 0° of extension', which requires a collateral ligament release to create a balanced and rectangular gap in 0° of extension (Figure 1)[1].

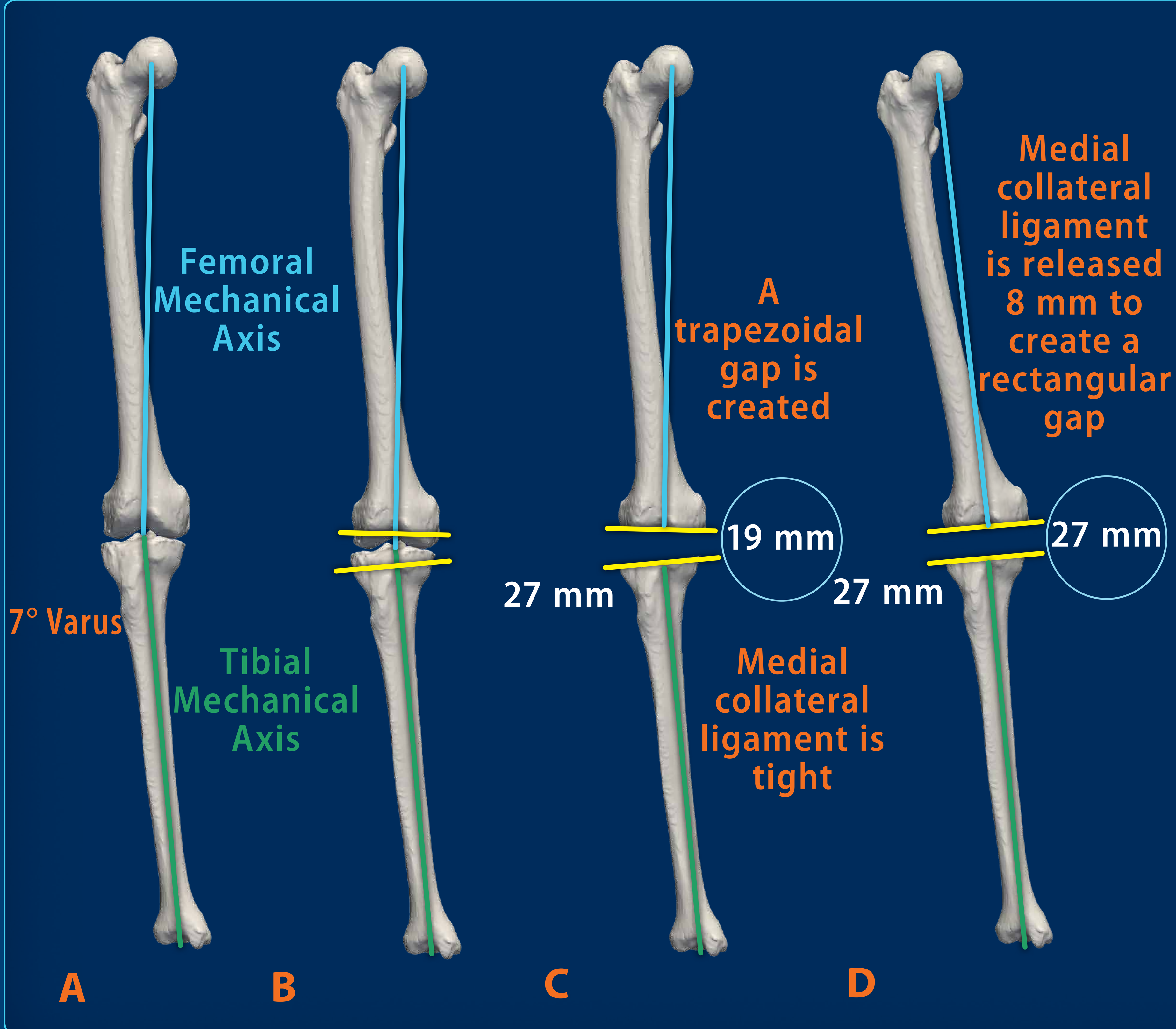

Figure 1. Illustration uses a normal right limb in 7° varus to show the method for aligning the normal limb to a 0° hip-knee-ankle angle, defining the side of the tight collateral ligament, and computing the magnitude of the collateral ligament release required to create a balanced and rectangular gap in 0° of extension.

A. The mechanical axis of the femur (blue line) and the mechanical axis of the tibia (green line) are drawn.

B. The distal femur and proximal tibia are cut perpendicular to their respective mechanical axes, which creates a trapezoidal gap (yellow lines).

C. In the lateral compartment, the thickness of the resections from the distal femur and proximal tibia totals 27 mm. In the medial compartment, the thickness of the resections from the distal femur and proximal tibia totals 19 mm.

D. An 8 mm release of the medial collateral ligament is needed to create a balanced and rectangular gap in 0° of extension.

After the limb is set at a 0° hip-knee-ankle angle, the surgeon can choose one of four methods to set the internal-external (I-E) rotation of the femoral component (Figure 2).

The second collateral ligament imbalance is recognized as 'instability in a compartment between 0° of extension and 90° of flexion that is uncorrectable by collateral ligament release' (Figure 3). This imbalance occurs in a compartment when the thickness of the distal and posterior femoral resections does not equal the thickness of the distal and posterior regions of the condyle of the femoral component after compensating for wear and kerf.

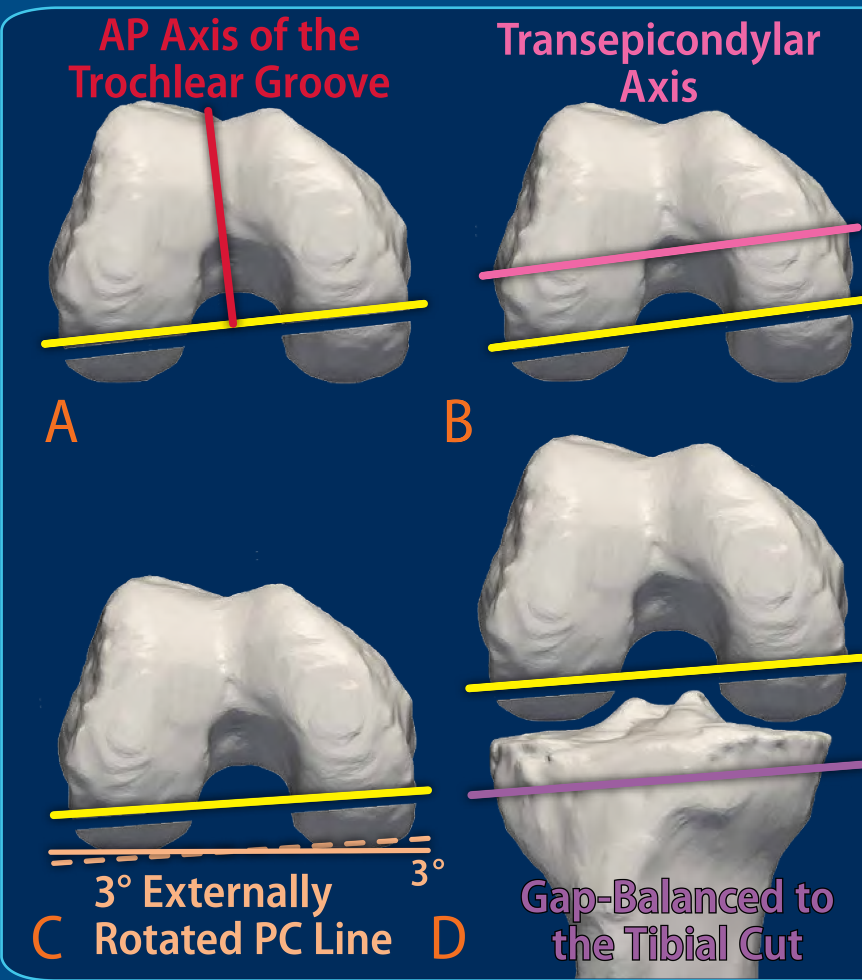

Figure 2. The I-E rotation of the femoral component can be set by cutting the femur (yellow line) using one of the four methods:

A. Perpendicular to the anteroposterior (AP) axis of the trochlear groove (Whiteside's line) (red)[4]

B. Parallel to the transepicondylar axis (pink)[5]

C. Parallel to a line 3° externally rotated (solid orange) to the posterior condylar line (dotted orange)[6]

D. Parallel to the tibial resection at 90° of flexion with the use of gap-balancing (purple)[7]

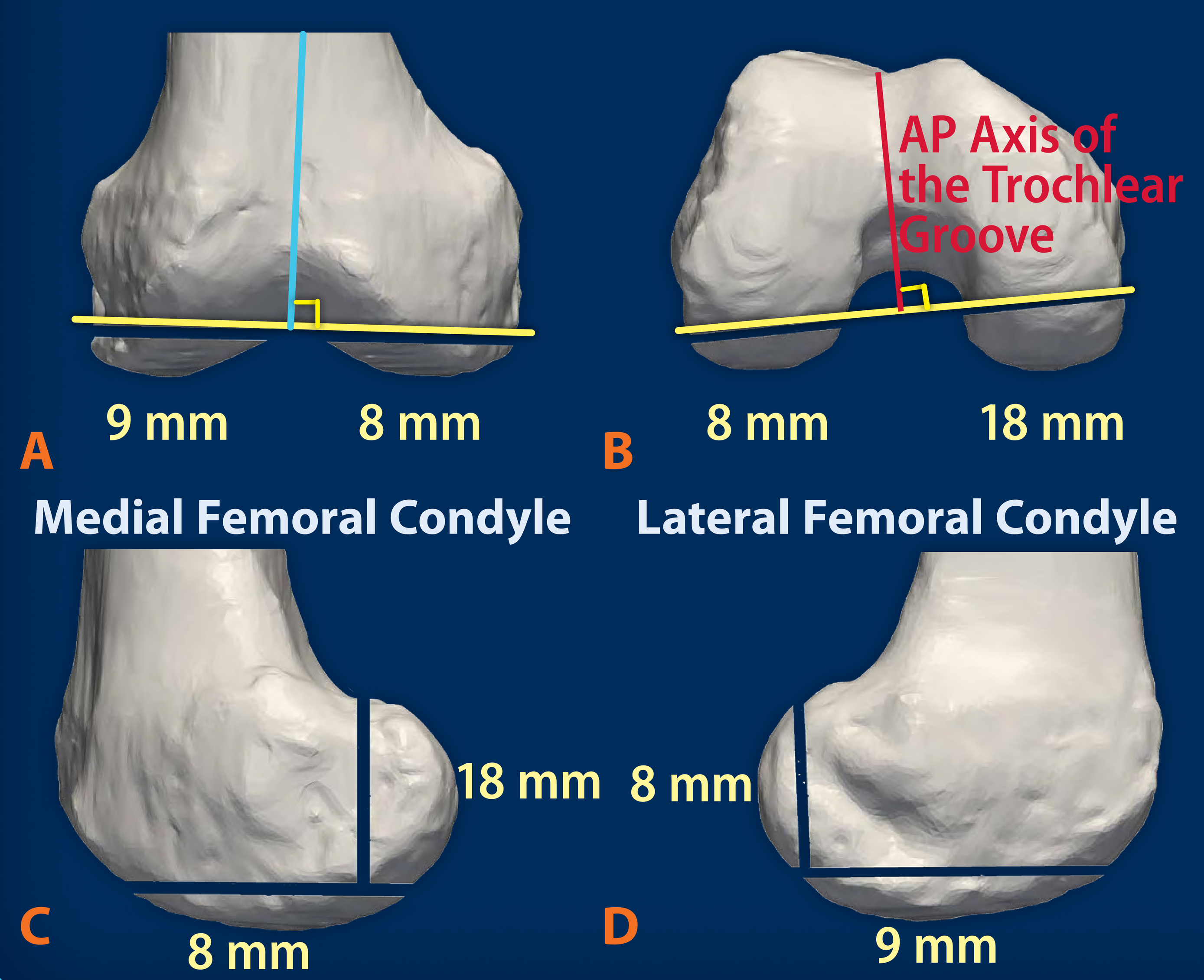

FIGURE 3. **Composite shows the method for computing the instability in a compartment between 0° extension and 90° flexion uncorrectable by collateral ligament release.**

A. The distal femoral cut was perpendicular to the femoral mechanical axis.

B. The posterior femoral cut was perpendicular to the AP axis.

C. In this example, the medial compartment had 10 mm of instability in 90° of flexion that is uncorrectable by collateral ligament release because the posterior resection was 10 mm thicker than the distal resection.

D. The lateral compartment had 1 mm of instability in 0° of extension that is uncorrectable by collateral ligament release because the distal resection was 1 mm thicker than the posterior resection.

PURPOSE

This study determined the frequency that mechanically aligning the TKA with the limb set at a 0° hip-knee-ankle angle with four different methods for setting I-E rotation of the femoral component created a tight collateral ligament at 0° of extension, an instability in a compartment between 0° of extension and 90° of flexion that is uncorrectable by collateral ligament release, and a change in limb and knee alignment from normal.

METHODS AND MATERIALS

1 Fifty three-dimension bone models of normal lower extremities from white subjects were created from computer tomograms with a slice thickness of 1 mm.

2 The simulation of mechanically aligning the TKA with the limb set at a 0° hip-knee-ankle angle was performed using image analysis software with the normal lower extremity projected in three kinematic planes (Paraview, Kitware Inc.) (Figure 4).

3 A femoral component with 8-mm thick distal and posterior regions on the medial and lateral femoral condyles and a tibial component with 9-mm thick medial and lateral condyles were used for the simulation. The minimum resection was 8 mm on the femur and 9 mm on the tibia.

4 The limb was set at a 0° hip-knee-ankle angle. The side of the tight collateral ligament was determined, and the magnitude of the collateral ligament release required to create a balanced and rectangular gap in 0° of extension was computed (Figure 1).

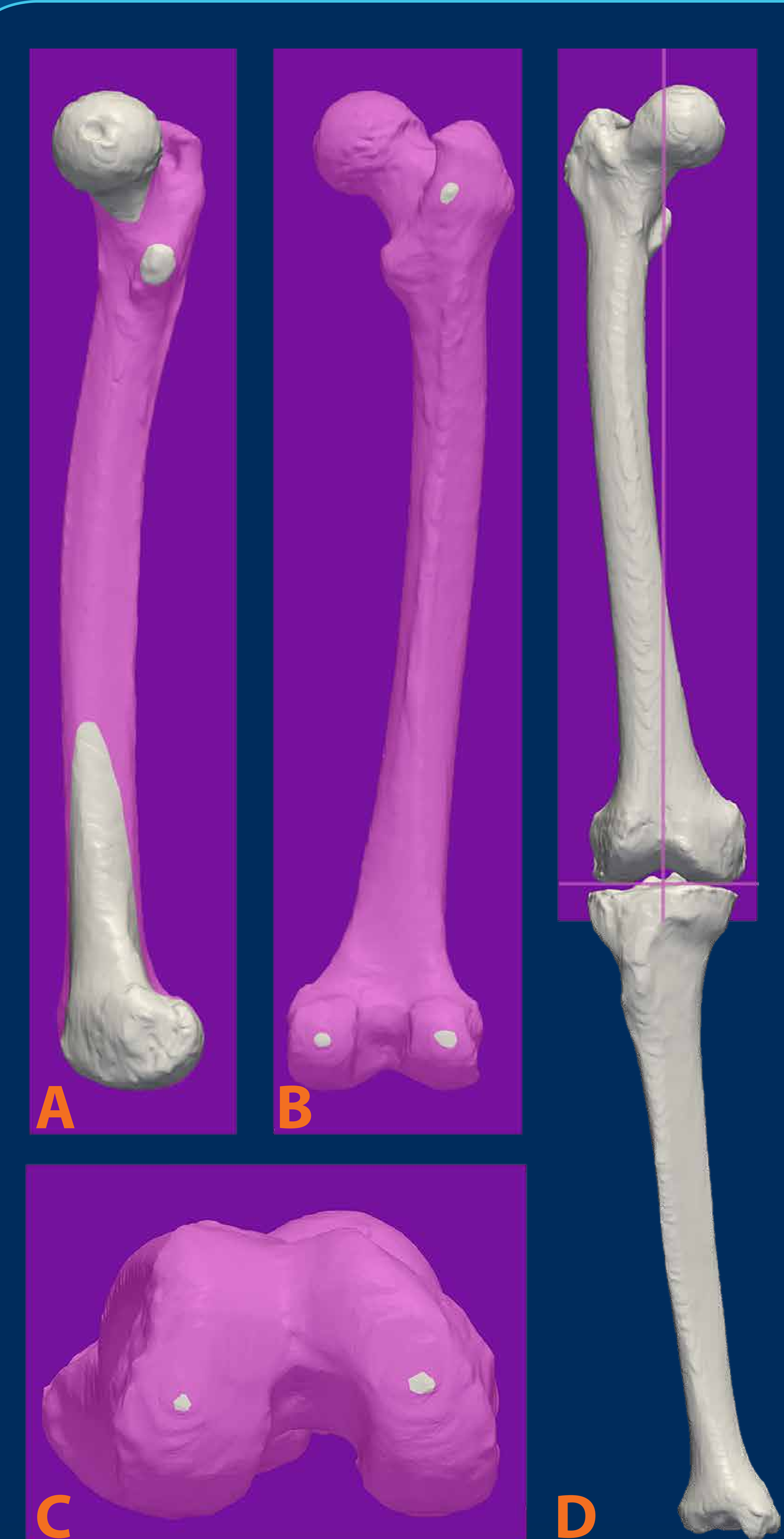

Figure 4. This composite shows the method for aligning a normal lower extremity in the sagittal, coronal, and axial kinematic planes.

A. The femur was projected in the sagittal kinematic plane by superimposing the medial and lateral femoral condyles.

B. 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.

C. The femur was projected in the axial kinematic plane and perpendicular to other two planes by placing the most distal point of each femoral condyle tangent to a surface

D. The transformations that aligned the femur to the kinematic planes were then applied to the tibia.

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METHODS AND MATERIALS

5 The I-E rotation of the femoral component was set to each of four femoral reference lines and the instability in each compartment between 0° of extension and 90° of flexion that is uncorrectable by collateral ligament release was computed (Figure 2).

6 The change in limb and knee alignment was computed (Figure 5).

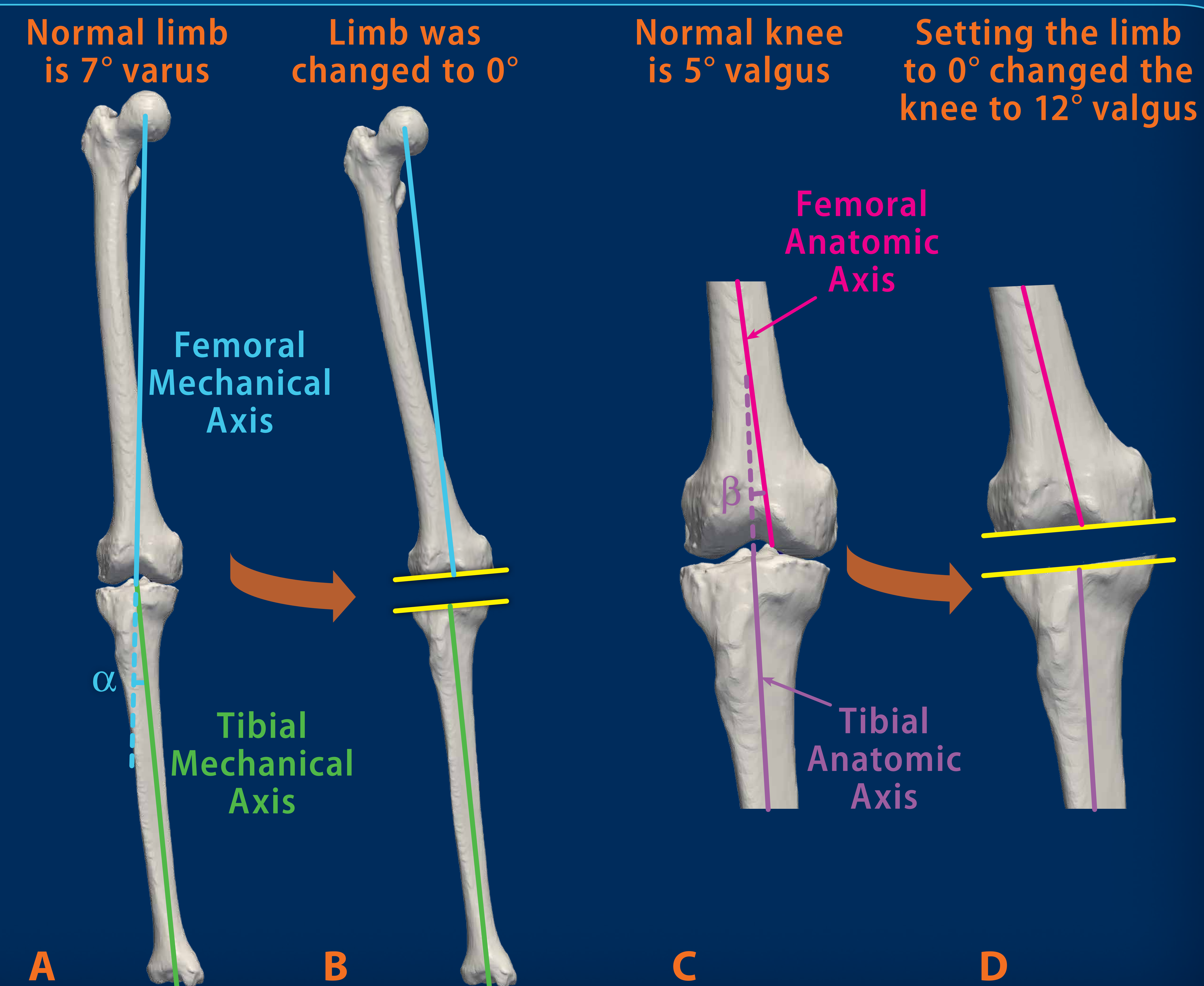
FIGURE 5. Composite uses a normal right lower extremity to show the method for determining the change in limb and knee alignment from normal after simulation of TKA.

A. The angle formed by the mechanical axes of the femur (blue line) and tibia (green line) determines limb alignment (α).

B. Cutting the bones perpendicular to their respective mechanical axes and releasing the tight collateral ligament at 0° extension changed the limb alignment to a 0° hip-knee-ankle angle (yellow line).

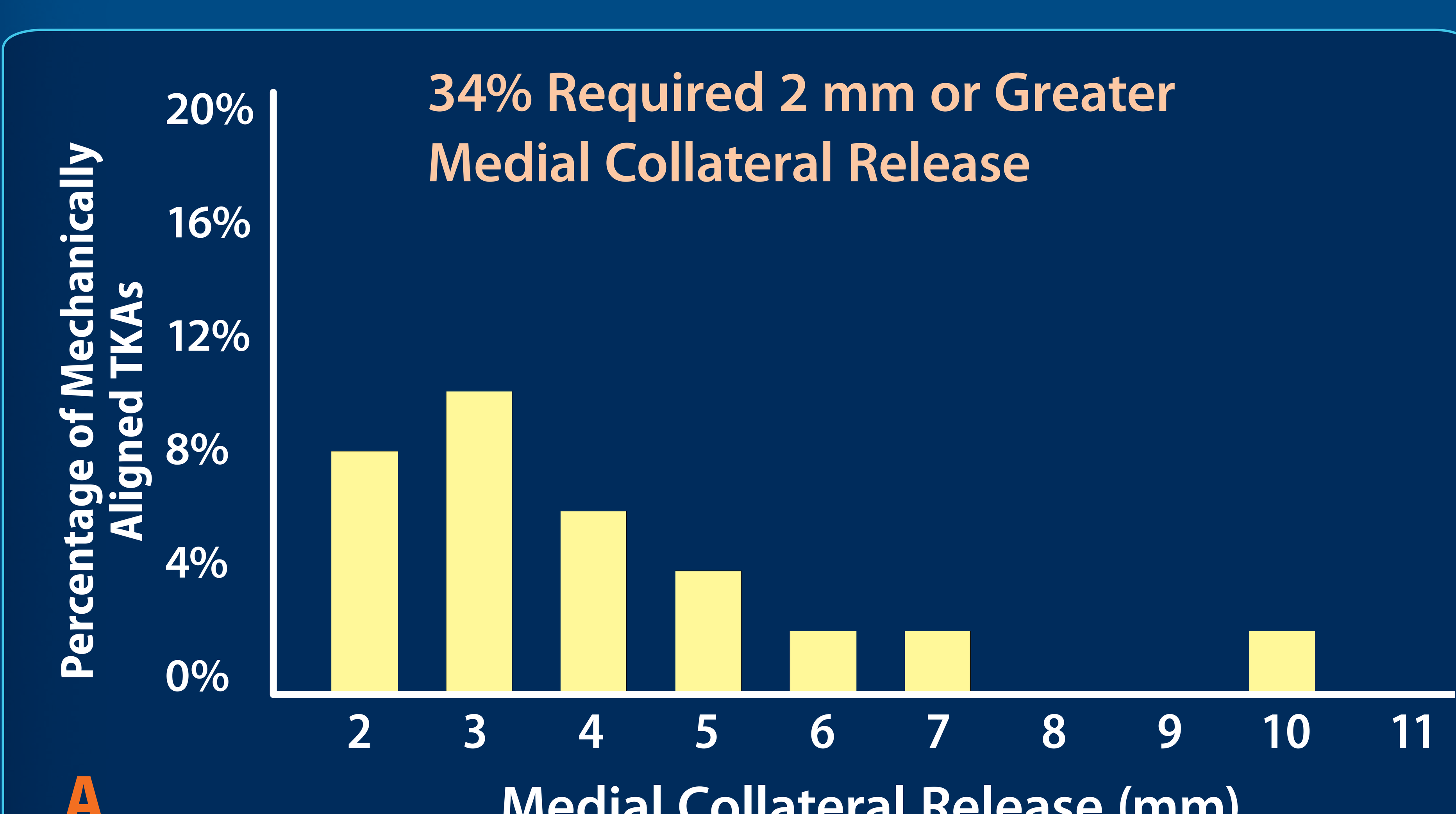
C. The angle formed by the anatomic axes of the femur (magenta line) and tibia (purple line) determines knee alignment (β).

D. Changing the limb to a 0° hip-knee-ankle angle changed the knee alignment from 5° valgus to 12° valgus.



RESULTS

Mechanically aligning the TKA with the limb at a 0° hip-knee-ankle angle using four different methods for setting I-E rotation of the femoral component frequently caused both types of collateral ligament imbalance and frequently changed limb and knee alignment from normal (Figures 6-8).



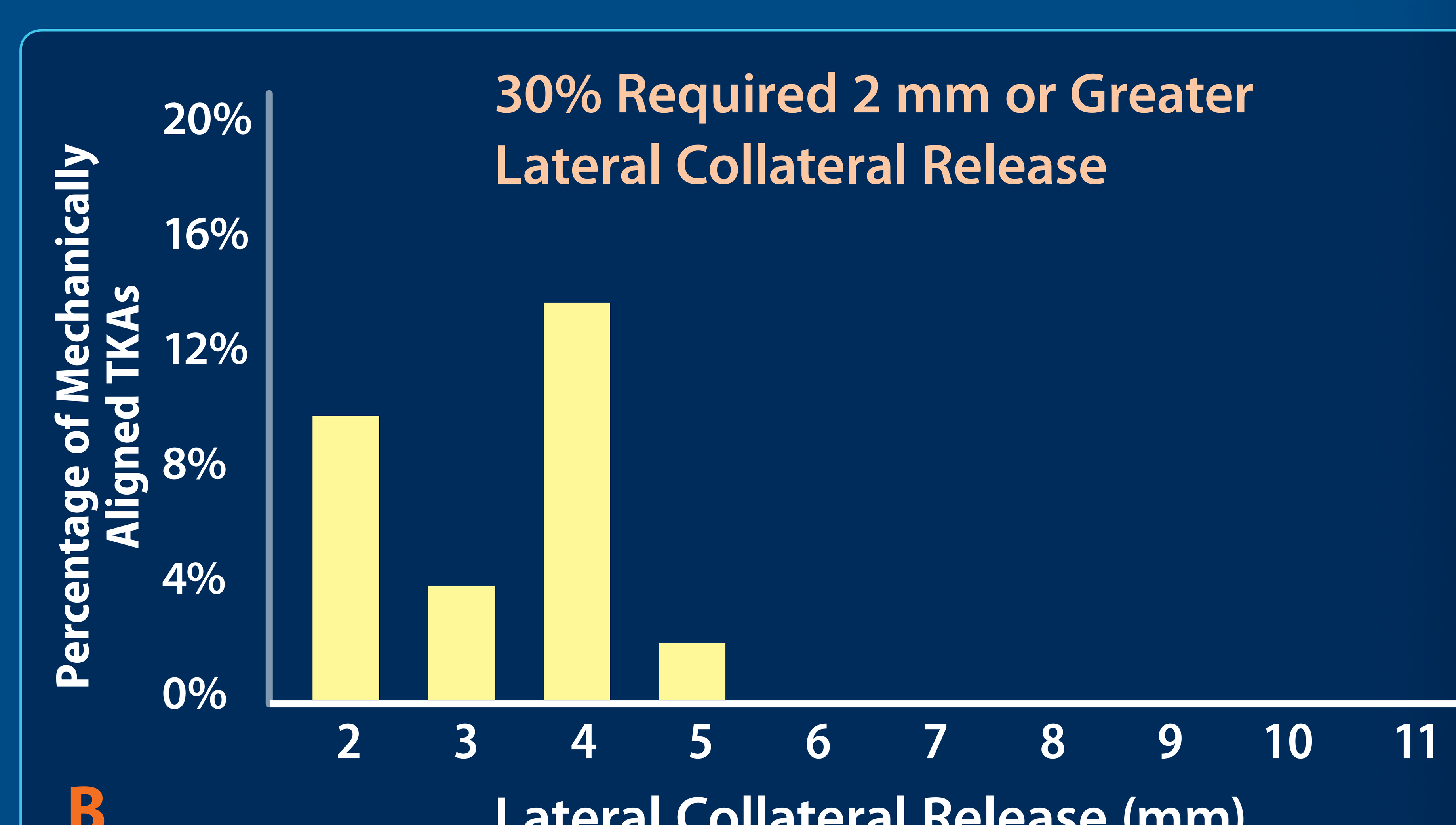


Figure 6. Column graphs show the percentage of simulated TKAs with the limb set at a 0° hip-knee-ankle angle requiring a 2 mm or greater release of the medial (A) or lateral (B) collateral ligament to correct a tight collateral ligament at 0° of extension.

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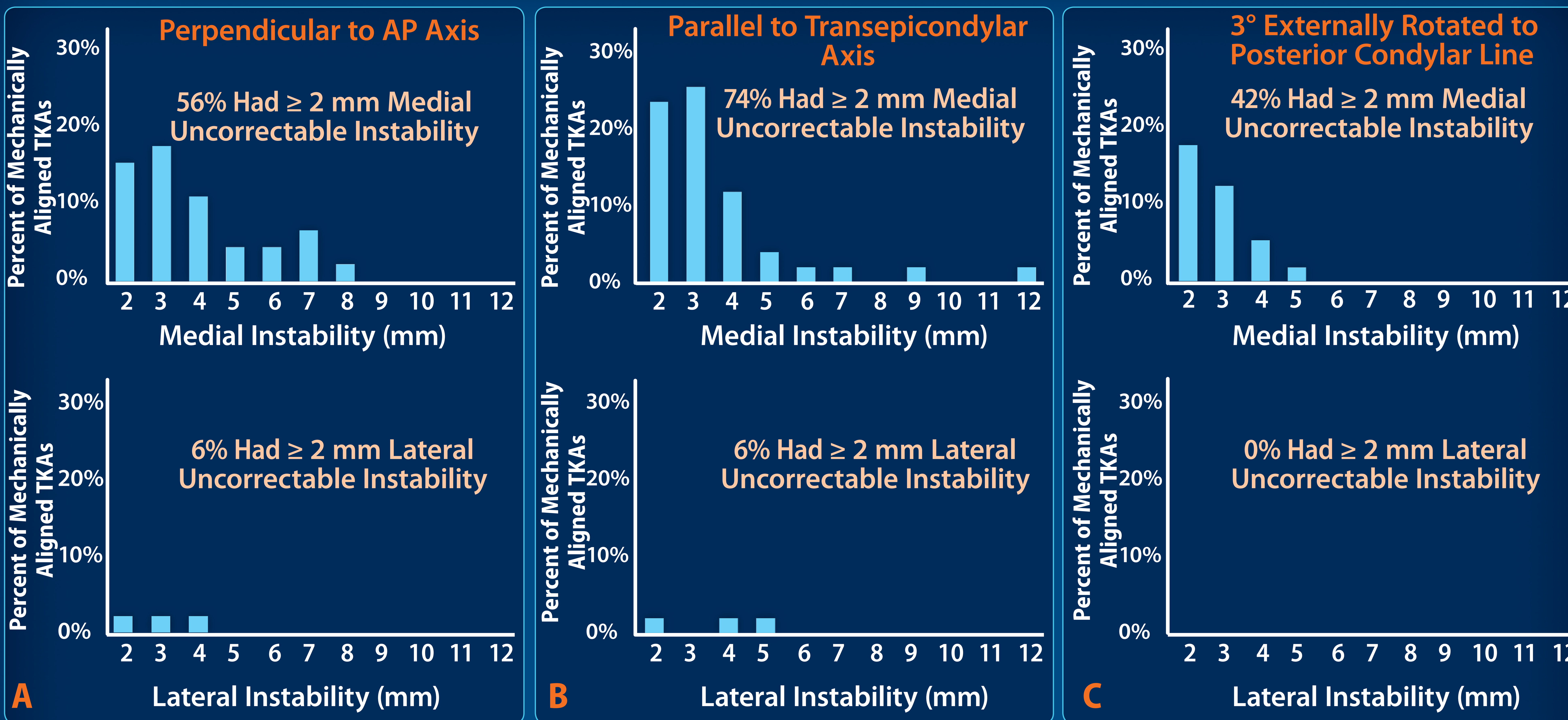

Figure 7. Column graphs show the percentage of mechanically aligned TKAs with the limb set at a 0° hip-knee-ankle angle that had a 2 mm or greater instability in a medial or lateral compartment between 0° of extension and 90° of flexion that is uncorrectable by collateral ligament release for three methods of setting the I-E rotation of the femoral component (A-C).

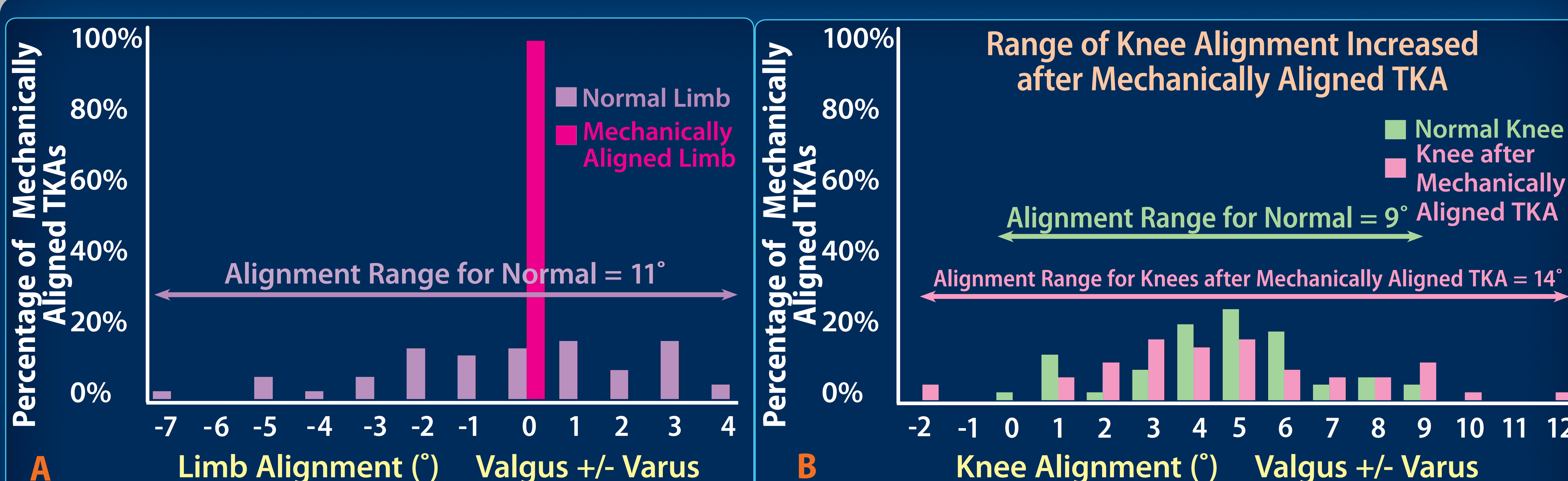

FIGURE 8. Column graphs show the frequency distributions of limb (A) and knee (B) alignment before and after mechanically aligned TKA with the limb set at a 0° hip-knee-ankle angle.

DISCUSSION

Surgeons that mechanically align the TKA with the limb set at a 0° hip-knee-ankle angle will frequently have to manage a wide range of instabilities that are complex, cumulative, and uncorrectable by collateral ligament release, and a wide range of changes in limb and knee alignment from normal. Patients who perceive these changes in stability, limb alignment, and knee alignment may be dissatisfied and require counseling.

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STUDY 2

How Frequently Does Mechanically Aligning a Total Knee Arthroplasty with the Knee Set at 5° or 7° Valgus Cause Collateral Ligament Imbalance and Change Alignment from Normal?

INTRODUCTION

Following TKA there is confusion regarding the criteria that should be used for assessing correct alignment of the components. One criterion investigated in Study 1 above is that the limb be set at a 0° hip-knee-ankle angle. Making this assessment requires a full-leg radiograph. Another criterion is that the femoral component be set at 5° or 7° valgus to the femoral anatomic axis and the tibial component be set perpendicular to the tibial anatomic axis because these component positions are considered well-aligned on a short radiograph of the knee[10,11]. However, aligning the TKA with the knee set at 5° or 7° valgus may cause undesirable consequences recognized as two types of collateral ligament imbalance and a change in the limb and knee alignment from normal.

This study determined the frequency that setting the knee at 5° or 7° valgus with four methods for setting I-E rotation of the femoral component caused these undesirable consequences.

METHODS AND MATERIALS

1 Fifty normal three-dimensional bone models of lower extremities from white subjects were created from computer tomograms with a slice thickness of 1 mm.

5 The I-E rotation of the femoral component was set with one of the four femoral reference lines, and the instability in a compartment between 0° of extension and 90° of flexion that is uncorrectable by a collateral ligament release was computed (Figure 2).

2 The simulation of mechanically aligning the TKA with the knee set at 5° or 7° valgus was performed using image analysis software with the normal lower extremity projected in the three kinematic planes (Figure 4).

3 A femoral component with 8-mm thick distal and posterior regions on the medial and lateral femoral condyles and a tibial component with 9-mm thick medial and lateral condyles were used for the simulation. The minimum resection was 8 mm on the femur and 9 mm on the tibia.

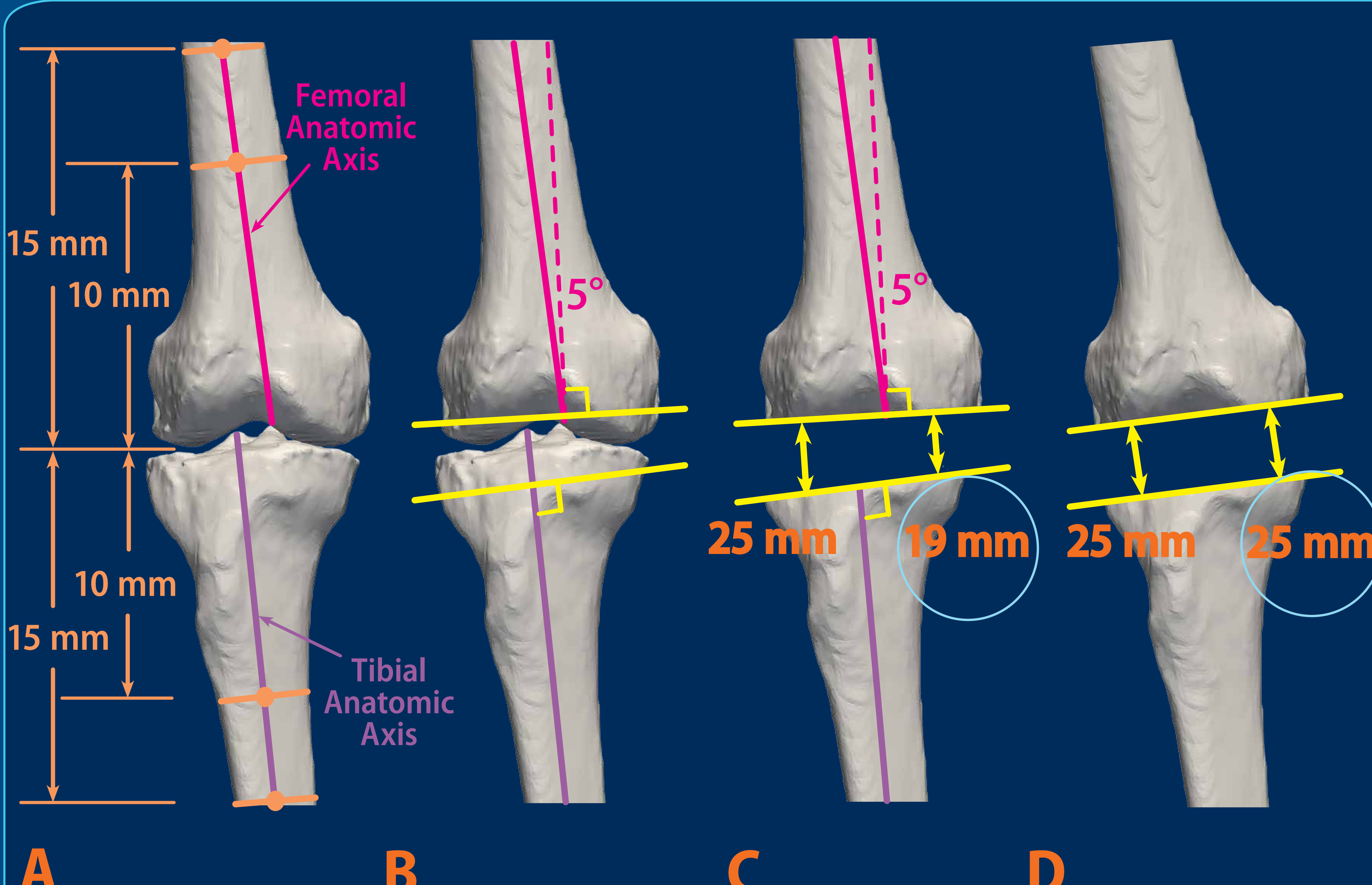

Figure 9. Composite uses a normal right knee in 7.9° valgus to show the method for setting the knee at 5° or 7° valgus. **A.** The anatomic axis of the femur **(magenta)** and the anatomic axis of the tibia **(purple)** are drawn. **B.** The distal femur is cut in 5° valgus to the femoral anatomic axis and the tibia is cut perpendicular to the tibial anatomic axis **(yellow)**. **C.** The total resections are 19 mm in the medial compartment and 25 mm in the lateral compartment. **D.** Releasing the lateral collateral ligament 6 mm creates a balanced rectangular gap and sets the knee alignment to 5° valgus. **E.** The same method was used to set the knee at 7° valgus.

4 The TKA was aligned with the knee in 5° or 7° valgus (Figure 9). The side of the tight collateral ligament was determined, and the magnitude of the collateral ligament release required to create a balanced and rectangular gap in 0° extension was computed (Figure 1).

6 The change in limb and knee alignment was computed (Figure 5).

RESULTS

Mechanically aligning the TKA with the knee set at 5° or 7° valgus with four different methods for setting I-E rotation of the femoral component frequently caused both types of ligament imbalances and frequently changed limb and knee alignment from normal (Figures 10-12).

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RESULTS

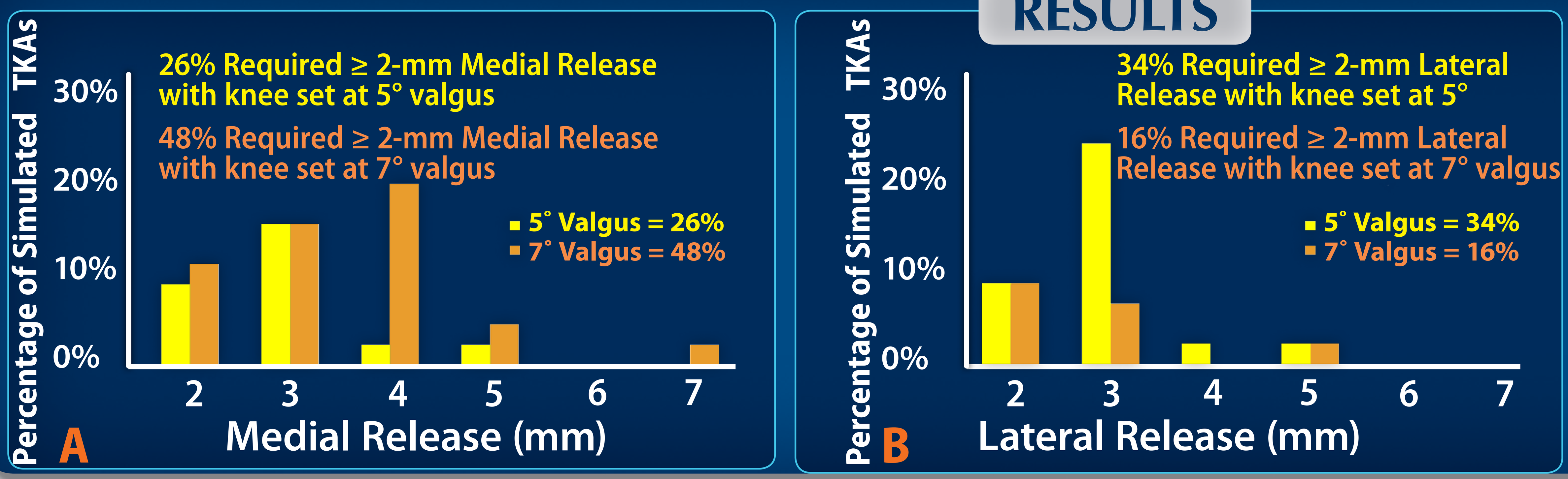

Figure 10. Column graphs show the percentage of simulated TKAs with the knee set at a 5° or 7° valgus with a 2 mm or greater release of the medial (A) or lateral (B) collateral ligament to correct a tight collateral ligament at 0° of extension.

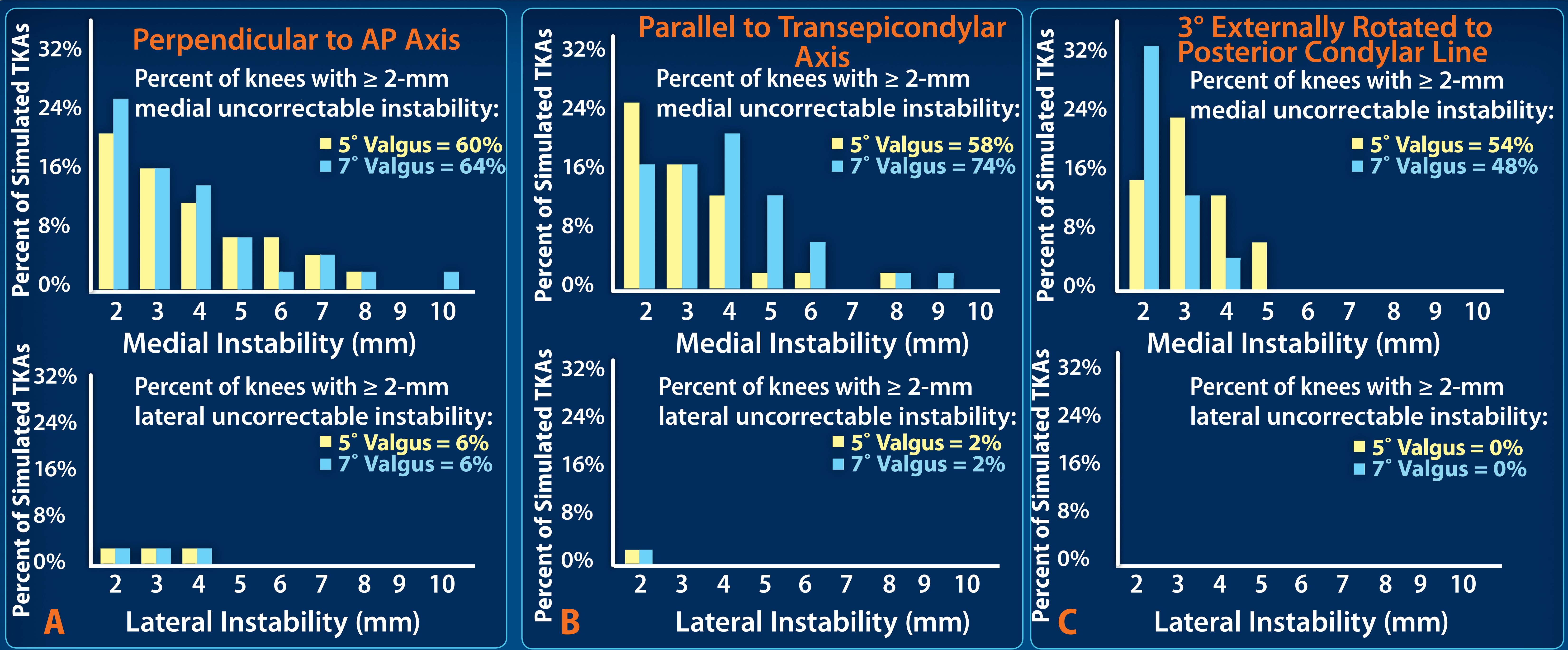

Figure 11. Column graphs show the percentage of simulated TKAs with the knee set at 5° or 7° valgus that had a 2 mm or greater instability in a medial and lateral compartment between 0° of extension and 90° flexion that is uncorrectable by collateral ligament release for three methods of setting the I-E rotation of the femoral component (A-C).

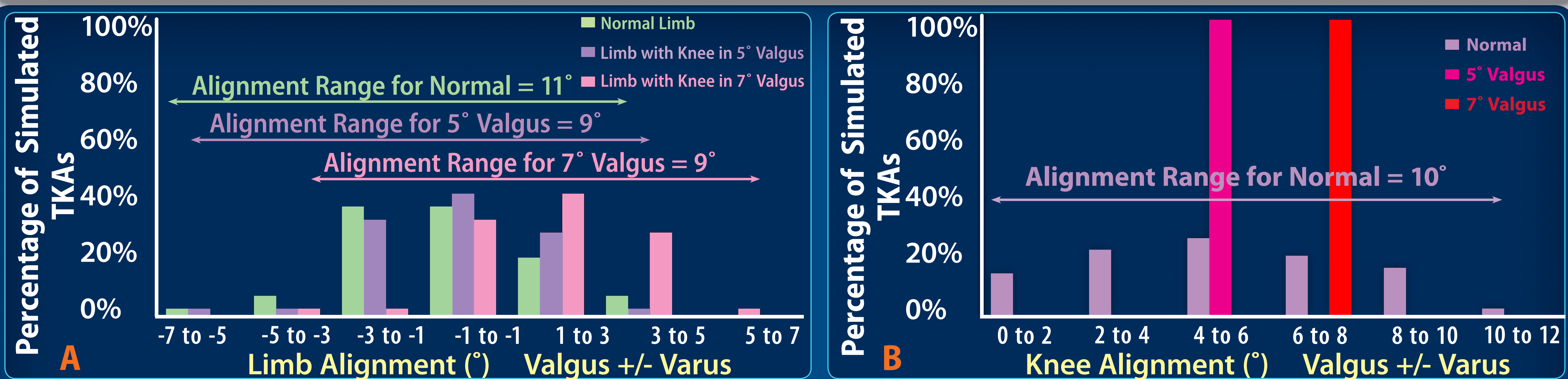

Figure 12. Column graphs show the frequency distributions of limb and knee alignment before and after mechanically aligned TKA with the knee set at 5° and 7° valgus.

DISCUSSION

Surgeons that mechanically align the TKA with the knee set at 5° or 7° valgus will frequently have to manage a wide range of instabilities that are complex, cumulative, and uncorrectable by collateral ligament release, and a wide range of changes in limb and knee alignment from normal. Patients who perceive these changes in stability, limb alignment, and knee alignment may be dissatisfied and require counseling.

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STUDY 3

How Frequently Does Kinematically Aligning a Total Knee Arthroplasty Cause Collateral Ligament Imbalance and Change Alignment from Normal?

BACKGROUND

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[2,3]. The alignment goal of kinematically aligned TKA is to position the components to resurface the articular surfaces of the knee which restores the natural angle and level of the joint lines and should closely restore the kinematic axes of the knee to normal[12] . However, whether kinematically aligned TKA causes two types of collateral ligament imbalance and changes the alignment of the limb and knee from normal is unknown.

PURPOSE

The present study determined the frequency that kinematically aligning a TKA creates a tight collateral ligament at 0° of extension, creates instability in a compartment between 0° of extension and 90° of flexion that is uncorrectable by collateral ligament release, and changes limb and knee alignment from normal.

METHODS AND MATERIAL

1 Fifty three-dimensional bone models of normal lower extremities from white subjects were created from computer tomograms with a slice thickness of 1 mm.

2 Kinematically aligned TKA was simulated using image analysis software (Paraview, Kitware inc.) with the normal lower extremity projected in the three kinematic planes (Figure 4).

3 A femoral component with 8-mm thick distal and posterior regions on the medial and lateral femoral condyles and a tibial component with 9-mm thick medial and lateral condyles were used for the simulation (Figure 13).

4 The collateral ligament release required to create a balanced and rectangular gap in 0° of extension, the instability in a compartment between 0° of extension and 90° of flexion that is uncorrectable by a collateral ligament release, and the change in limb and knee alignment were computed (Figures 1, 3 and 5).

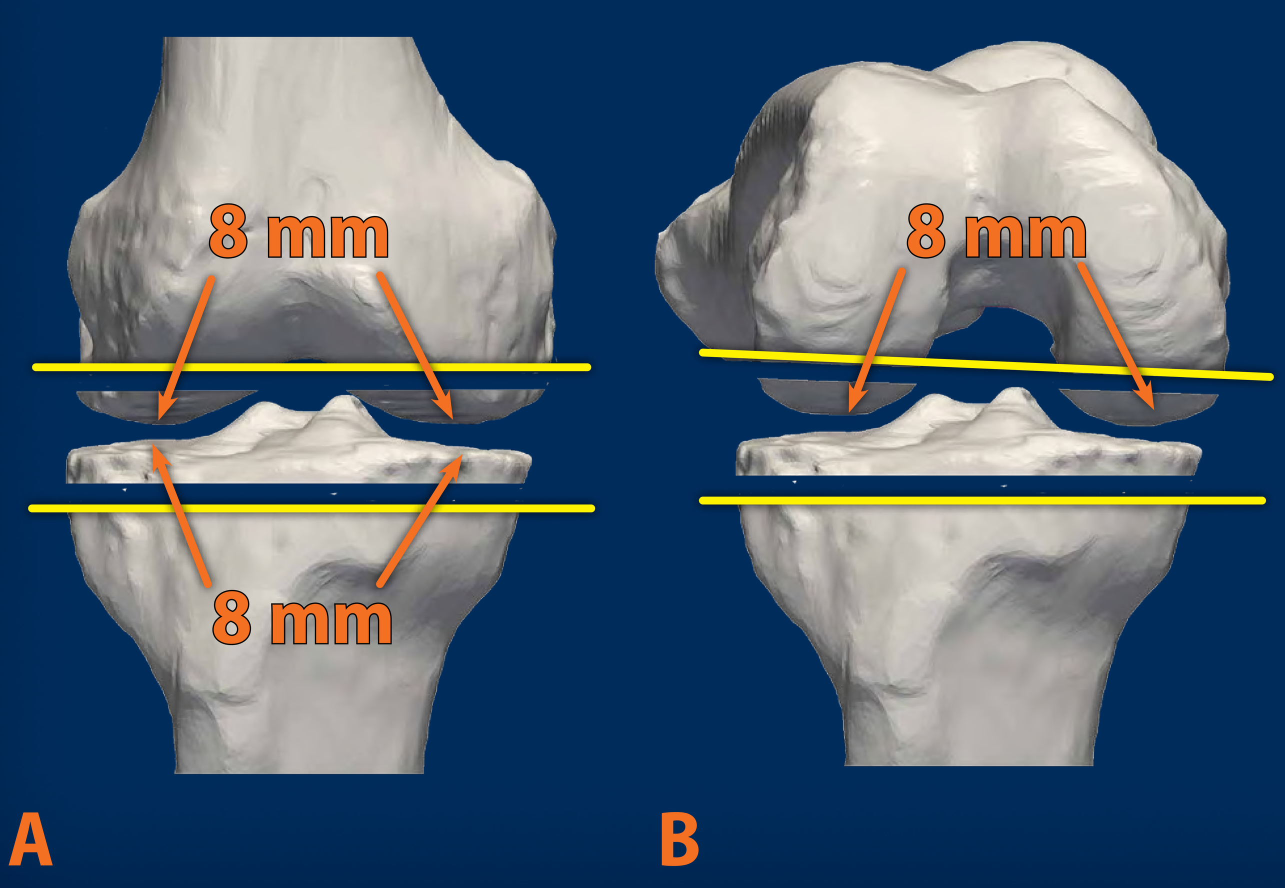

Figure 13. Composite shows the methods for kinematically aligning the TKA.

A. The femoral component was aligned in the coronal plane by resecting 8 mm of bone from the distal medial and lateral femoral condyles. The tibial component was aligned by resecting 9 mm of bone from the medial and lateral tibial condyles.

B. The I-E rotation of the femoral component was set in the axial plane by resecting 8 mm of bone from the posterior medial and lateral femoral condyles.

RESULTS

Kinematically aligned TKA:

- Did not cause a tight collateral ligament at 0° of extension.
- Did not cause instability in a compartment between 0° of extension and 90° of flexion that is uncorrectable by collateral ligament release.
- Did not change limb and knee alignment from normal.

DISCUSSION

Kinematically aligned TKA did not cause collateral ligament instability or change limb and knee alignment from normal, which explains in part why patients treated with kinematically aligned TKA report better satisfaction and function at 2 years and have a lower revision rate at 3 years than patients treated with mechanically aligned TKA[2,3].

SUMMARY OF SCIENTIFIC EXHIBIT

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1 Surgeons should be aware that when they mechanically align a TKA with the limb set at a 0° hip-knee-ankle angle, the knee set at 5° valgus, or the knee set at 7° valgus with four different methods for setting I-E rotation of the femoral component, they will frequently have to manage:

- A wide range of instabilities that are complex, cumulative, and uncorrectable by collateral ligament release
- A wide range of changes in limb and knee alignment from normal

2 Kinematically aligned TKA avoids these undesirable changes in stability and alignment, which explains in part why patients with kinematically aligned TKA have better satisfaction, function scores, and flexion than those with mechanically aligned TKA[2,3].

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