SE 45

Principle, History, Surgical Technique, and Results of Kinematic Alignment: An Alignment Option for Total Knee Arthroplasty

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OVERVIEW

The goal of this scientific exhibit is to encourage surgeons to consider kinematic alignment when performing total knee arthroplasty (TKA). This scientific exhibit:

- Describes normal knee kinematics and the principle and history of kinematically aligned TKA
- Presents the technique to position the femoral and tibial components and two intraoperative checks that verify kinematic alignment of the femoral and tibial components with generic instruments
- Explains the simple step-wise algorithm that balances the kinematically aligned TKA without releasing collateral ligaments
- Presents the results of three studies that evaluated patient satisfaction, function, alignment, risk of component failure, and contact kinematics after kinematically aligned TKA

NORMAL KNEE KINEMATICS

The interaction between the ligaments, menisci, and articular surfaces of the femur, tibia, and patella determine the kinematics of the normal knee[1]. Three kinematic axes, which are parallel or perpendicular to the natural joint lines, describe normal knee kinematics[2-4] (Figure 1).

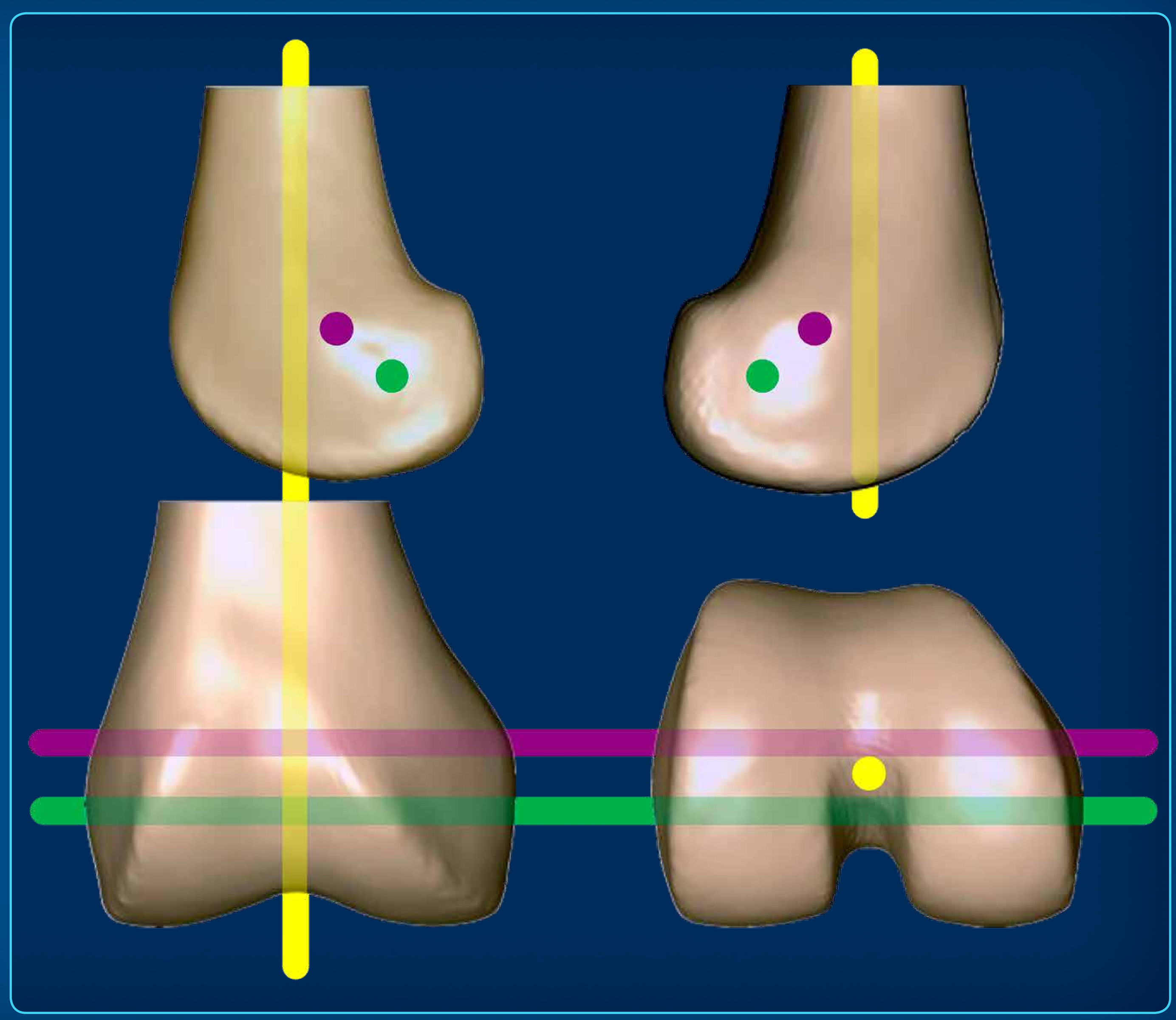

Figure 1. The composite shows four views of the distal femur and the three kinematic axes of the knee, which are parallel or perpendicular to the natural joint lines. The green line indicates the transverse axis in the femur about which the tibia flexes and extends. The magenta line indicates the transverse axis in the femur about which the patella flexes and extends. The yellow line indicates the longitudinal axis in the tibia about which the tibia internally-externally rotates on the femur.

PRINCIPLE OF KINEMATICALLY ALIGNED TKA

In kinematically aligned TKA, the surgeon positions the femoral and tibial components to resurface the articular surfaces, restore the natural angle and level of the joint lines, and minimize ligament release (Figure 2).

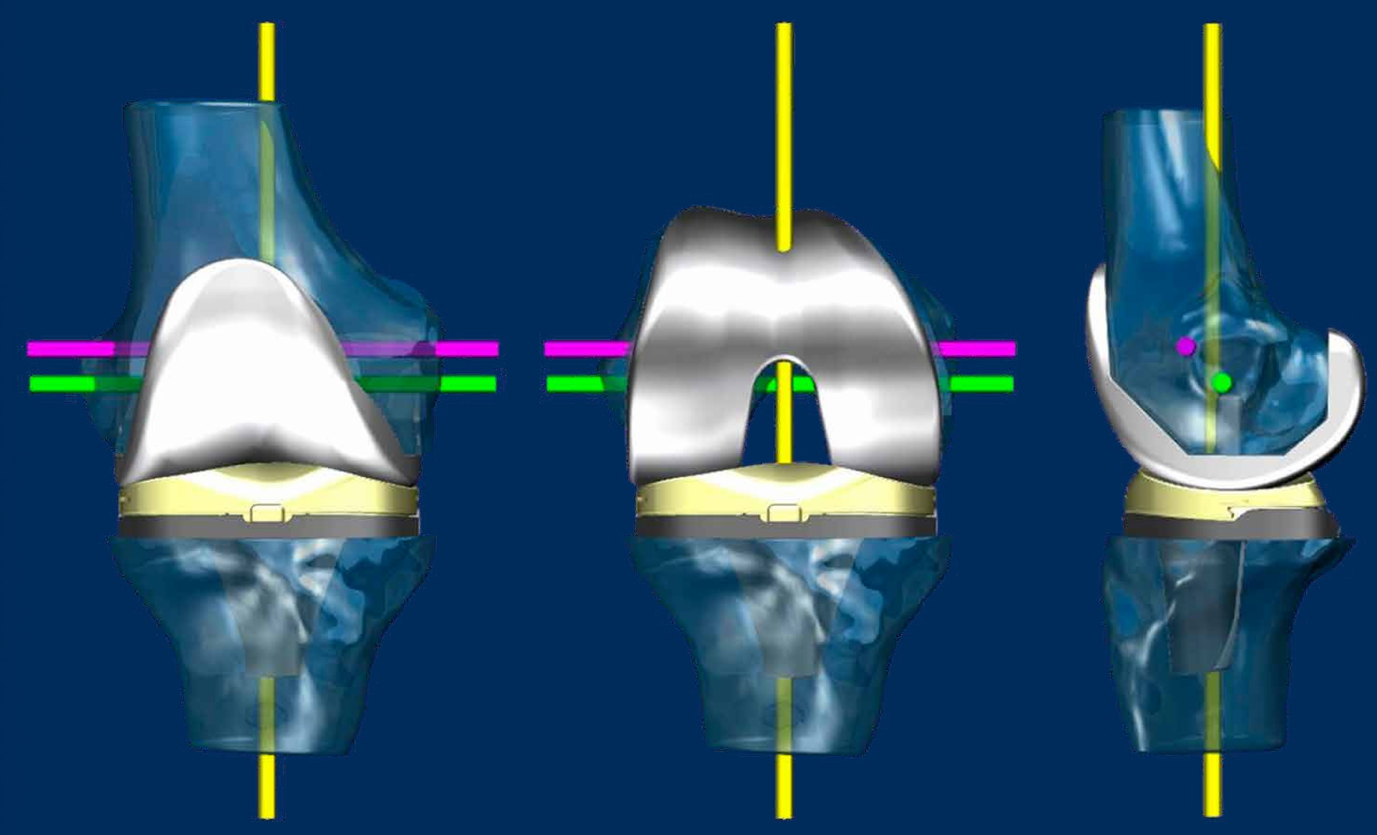

Figure 2. Composite shows three views of the femoral and tibial components positioned to resurface the articular surfaces of the knee. Resurfacing the articular surfaces restores the natural angle and level of the joint lines, which are parallel or perpendicular to the natural kinematic axes. Removing osteophytes restores the natural length of the collateral, retinacular, and posterior cruciate ligaments, which minimizes the need for release[5,6].

Balancing the kinematically aligned TKA requires understanding that the natural varus-valgus (V-V) laxity at 0° of extension is different from that at 90° of flexion in the normal knee. Kinematically aligned TKA maintains the natural difference in V-V laxity between 0° of extension and 90° of flexion (Figure 3). Gap-balancing changes the V-V laxity at 90° of flexion to match that at 0° of extension, which is unnatural, over-tightens the knee, and may cause stiffness, limited flexion, abnormal kinematics, and accelerated polyethylene wear.

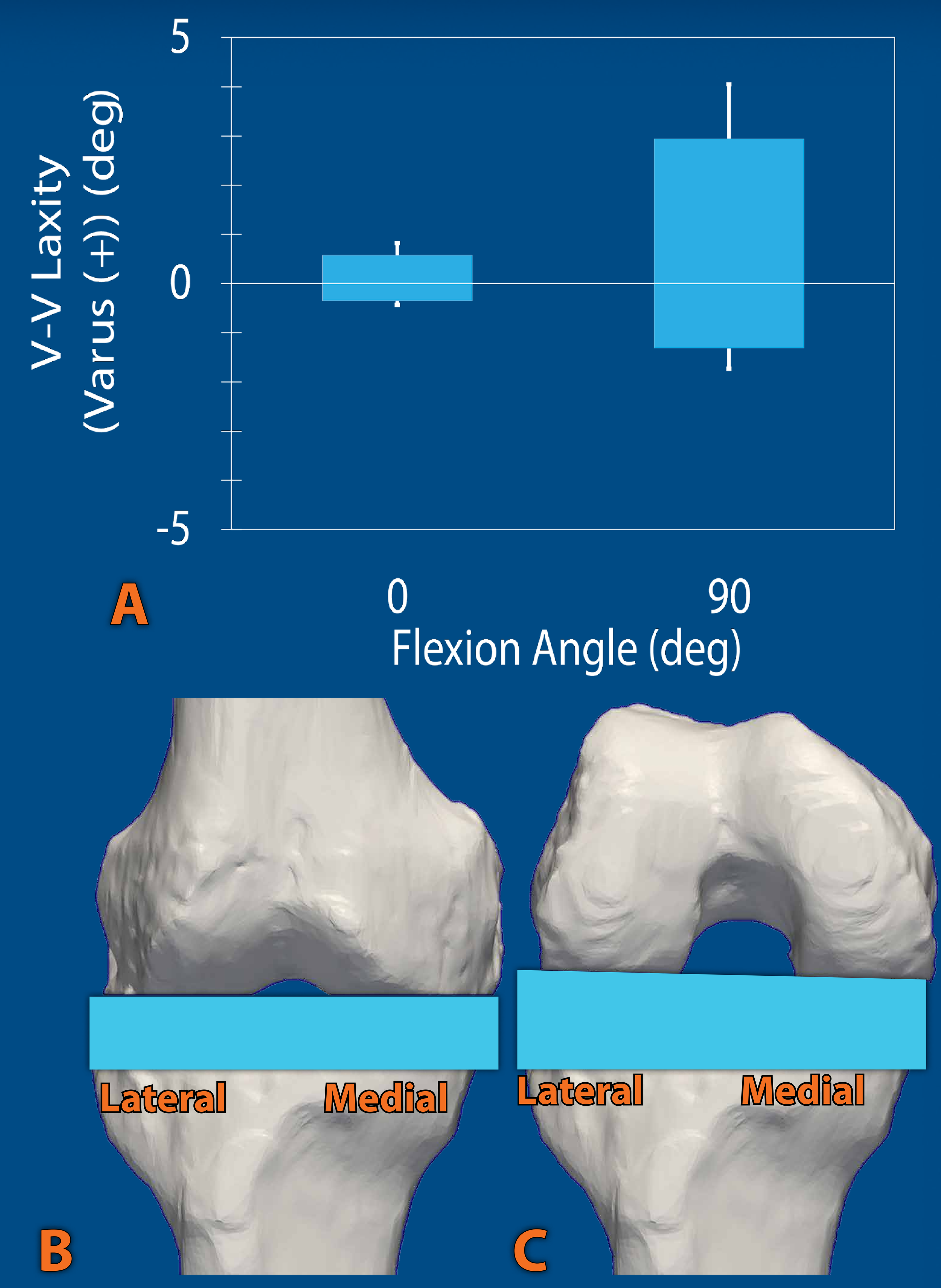

Figure 3. Column graph of the V-V laxity of the knee shows the symmetric and negligible V-V laxity at 0° of extension, which is different from the asymmetric and greater V-V laxity at 90° of flexion (error bars +/- standard deviation)[7] (A). To restore the natural difference in V-V laxity between 0° and 90° of flexion in TKA, the gap at 0° of extension should be rectangular (B) and the gap at 90° of flexion should be trapezoidal (i.e. larger laterally than medially) and should be larger than the gap at 0° of extension (C).

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HISTORY OF KINEMATICALLY ALIGNED TKA

Kinematically aligned TKA is predicated on the pioneering work of Hungerford, Kenna, and Krackow who designed the porous-coated anatomic (PCA) total knee system with the specific objective of restoring normal knee kinematics through minimal articular surface replacement. They devised an instrumentation system that allowed the ligaments to function under normal tension throughout the full range of motion, which minimized stresses on fixation and motion interfaces. Their system was approved by the Food and Drug Administration (FDA) and available for use in 1984[8, 9].

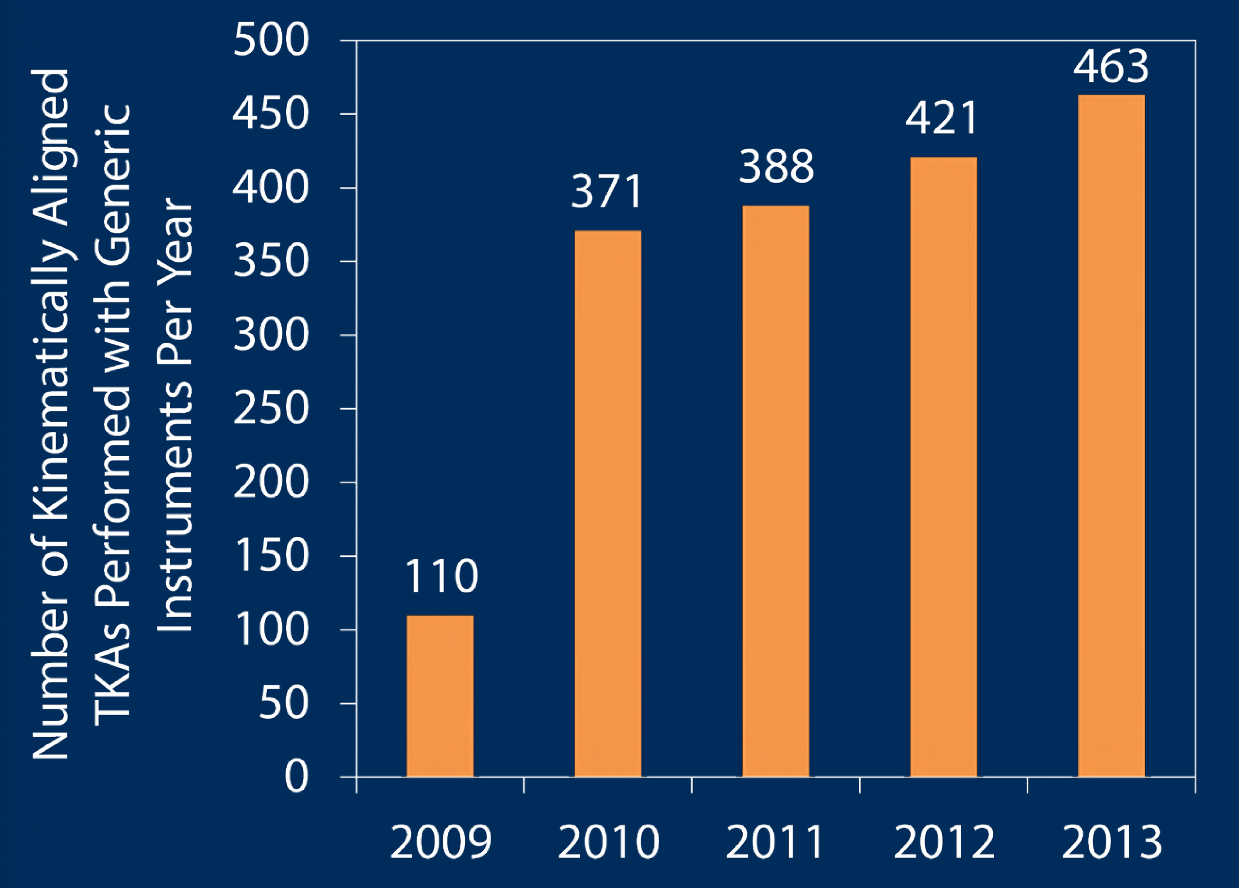

Figure 4. Column graph shows the steady growth in the number of kinematically aligned TKAs performed each year with generic instruments, which is attributed to high patient-reported satisfaction and function.

Kinematically aligned TKA was first performed in January 2006 with patient-specific instrumentation, and over 20,000 were performed in the United States between 2006 and 2009. In 2008, the potential for 'malalignment' with this system was reported by Klatt and Hozack based on navigated measurements of alignment in four patients without radiographic or clinical follow-up[10]. In September 2009, the FDA did not approve the use of patient-specific instrumentation to perform kinematically aligned TKA. Since September 2009, we have performed 1753 kinematically aligned TKAs with use of generic instruments similar in design and identical in function to those introduced by Hungerford et al (Figure 4)[8, 9].

TECHNIQUE FOR KINEMATICALLY ALIGNING THE FEMORAL COMPONENT

The technique for kinematically aligning the femoral component requires understanding that there are predictable patterns of cartilage wear and a lack of bone wear in the osteoarthritic knee with varus or valgus deformity[11] (Figure 6).

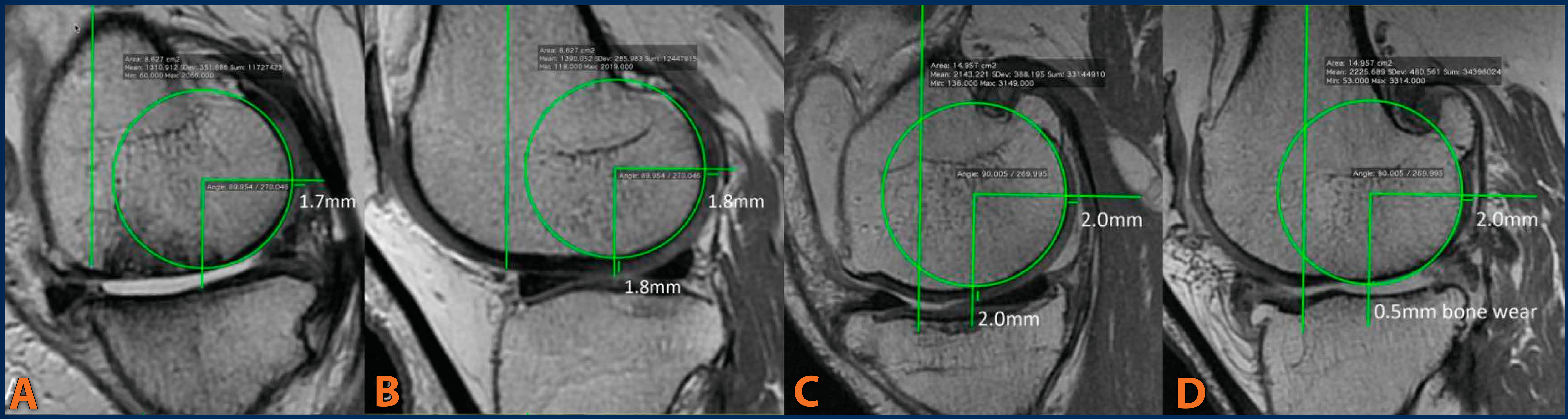

Figure 6. Magnetic resonance images show the (A) medial hemijoint and (B) lateral hemijoint of the typical varus osteoarthritic knee, and the (C) medial hemijoint and (D) lateral hemijoint of the typical valgus osteoarthritic knee. In the varus osteoarthritic knee, cartilage wear occurs on the distal medial condyle. In the valgus osteoarthritic knee, cartilage wear occurs on the distal lateral condyle. Cartilage wear averages 1.9 mm[11].

Which distal femoral condyle is worn is determined intraoperatively, and a distal intramedullary referencing guide is chosen to correct the cartilage wear (Figure 7).

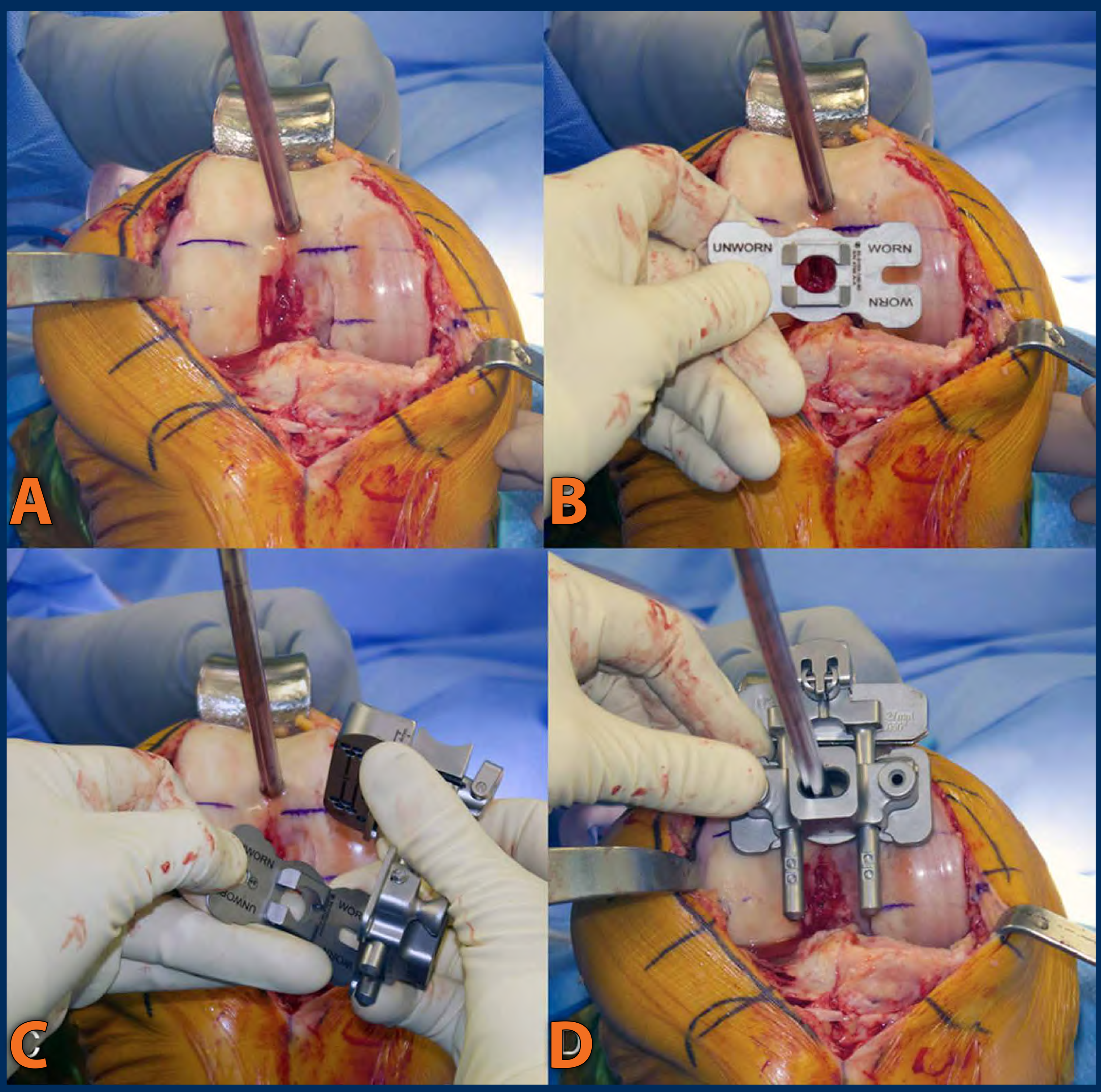

Figure 7. Composite of a right varus osteoarthritic knee shows the use of the distal intramedullary referencing guide to set V-V, flexion-extension, and proximal-distal translation of the femoral component (**A to D**). The worn side of the distal referencing guide (which corrects 2 mm of cartilage wear) contacts the worn distal condyle, and the unworn side contacts the unworn distal condyle.

The cartilage wear on the posterior femur is difficult to determine intraoperatively with the tibia unresected (Figure 8). An MRI review of osteoarthritic knees with varus or valgus deformities has shown that posterior cartilage wear is small and significantly less than distal cartilage wear[11].

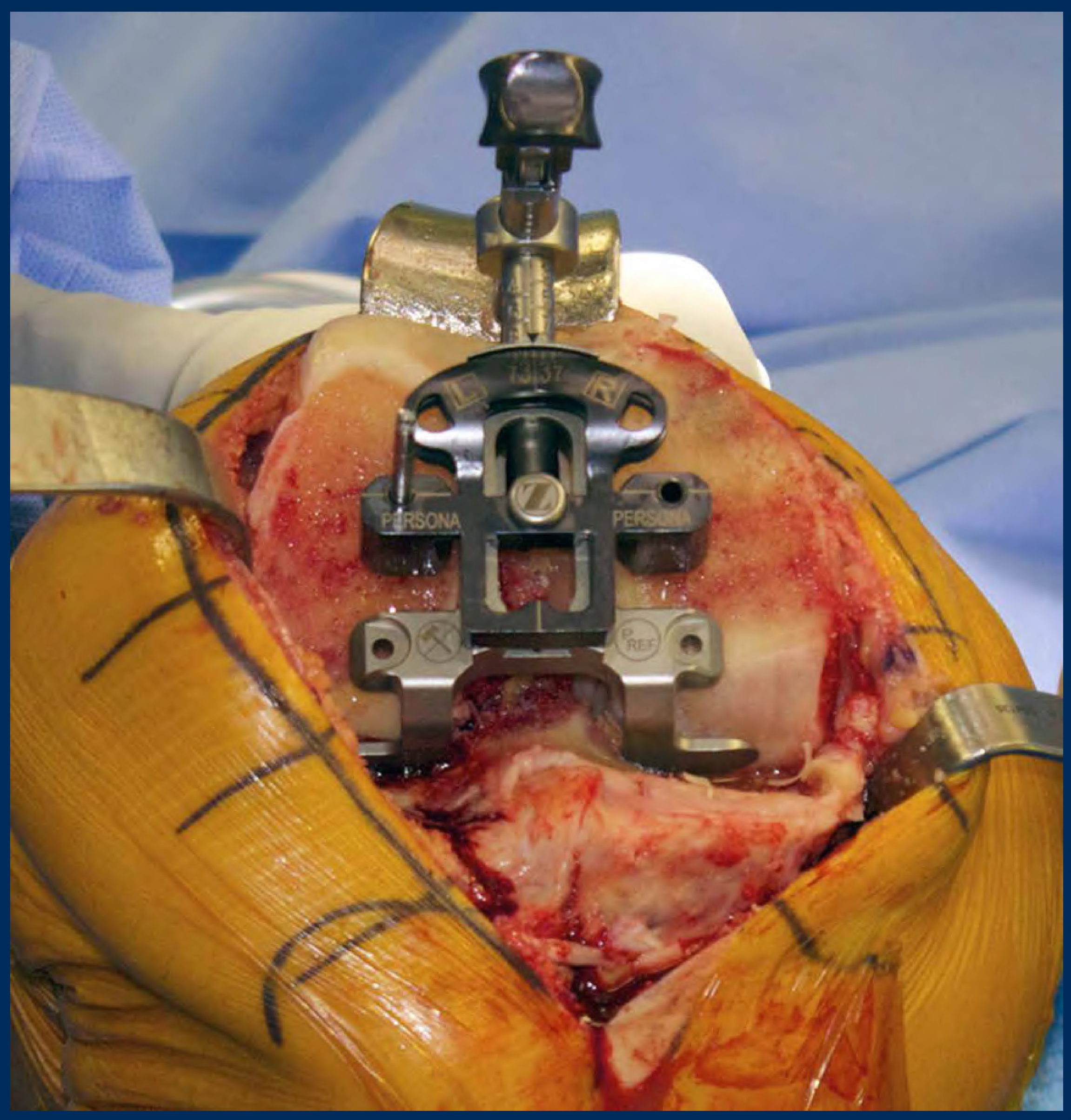

Figure 8. Photograph shows the use of the neutral posterior referencing guide to set internal-external (I-E) rotation and anterior-posterior (A-P) translation of the femoral component. The neutral posterior referencing guide is chosen because posterior cartilage wear is typically small and clinically unimportant.

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TECHNIQUE FOR KINEMATICALLY ALIGNING THE TIBIAL COMPONENT

The technique for kinematically aligning the V-V and posterior slope of the tibial component is performed with a generic extramedullary tibial guide (Figure 9).

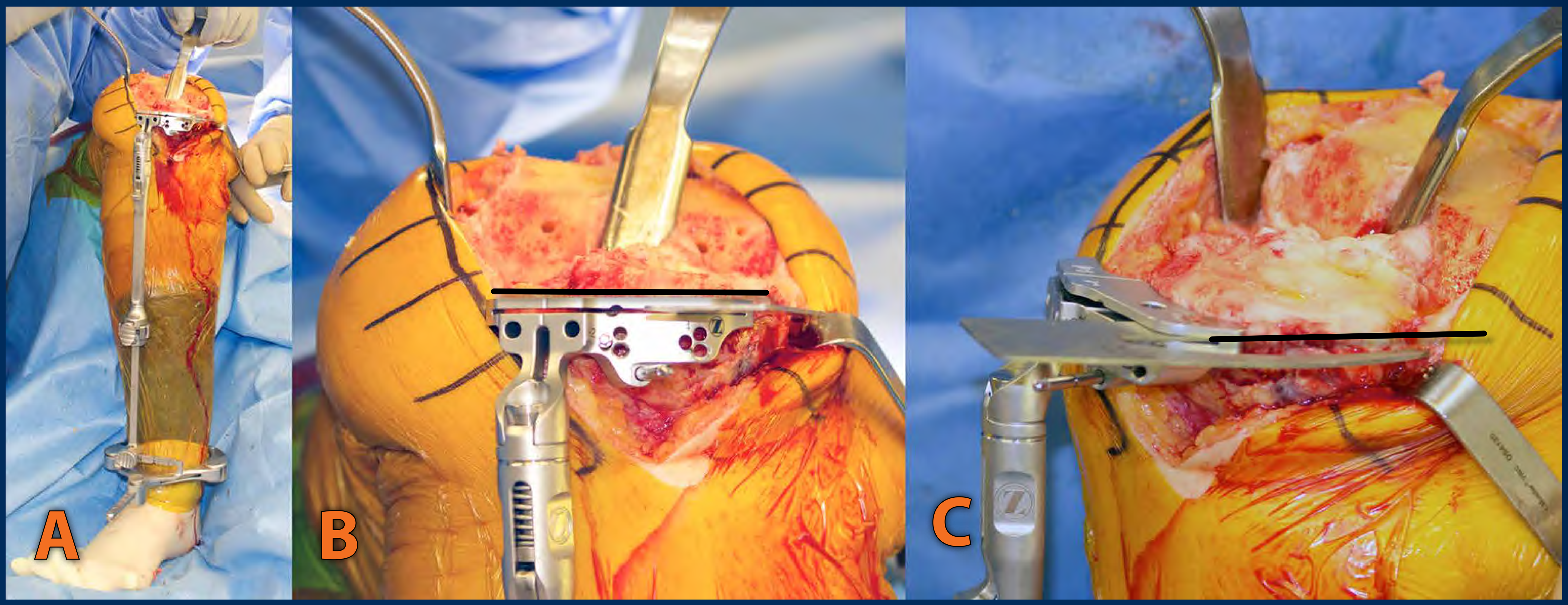

Figure 9. Composite of a right knee shows the extramedullary tibial guide (A). The cut plane of the proximal tibia is adjusted to 1) reproduce the natural V-V slope of the tibial articular surface (black line) after correcting for wear (B), 2) slightly reduce the normal posterior slope (black line) (C), and 3) remove a conservative thickness of bone to accept the thinnest tibial liner. These steps help preserve the insertion of the PCL.

The technique for kinematically aligning the internal-external (I-E) rotation of the tibial component is to set the anteroposterior (AP) axis of the tibial trial component parallel to the major axis of the nearly elliptical boundary of the lateral tibial condyle (Figure 10)[6, 12].

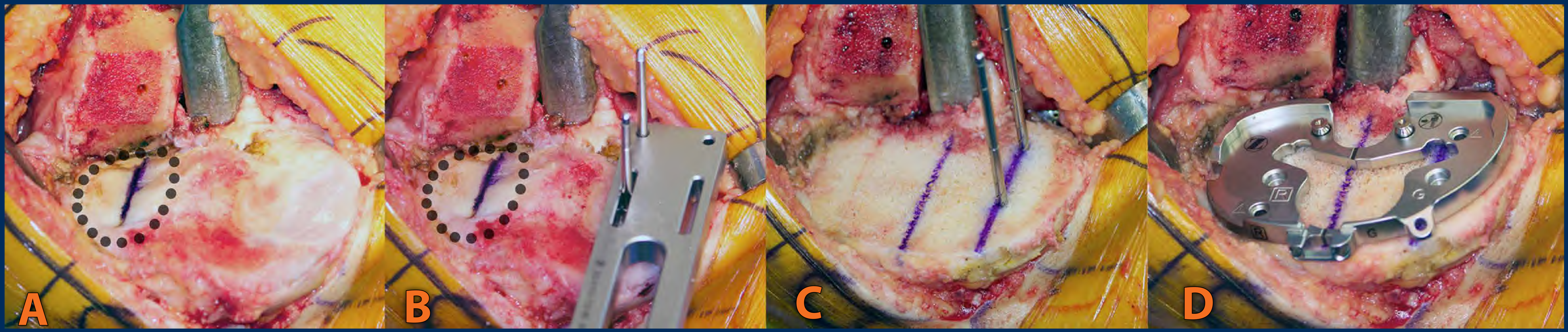

Figure 10. Composite of a right knee shows the steps for aligning the rotation of the tibial component on the tibia. (A) A series of black dots outline the boundary of the nearly elliptical-shaped lateral tibial condyle (black dots) and the major axis of the ellipse is drawn (blue line) . (B) Two pins are drilled parallel to the major axis with a guide. (C) On the cut surface of the tibial plateau, two lines are drawn parallel to the two drill holes. (D) The AP axis of the trial tibial baseplate is aligned parallel to these lines.

INTRAOPERATIVE CHECK FOR VERIFYING KINEMATIC ALIGNMENT OF THE FEMORAL COMPONENT

The intraoperative check for verifying kinematic alignment of the femoral component is matching the thickness of each of the distal and posterior femoral resections to their respective regions on the condyle of the femoral component after correcting for cartilage wear and kerf (Figure 11)[6].

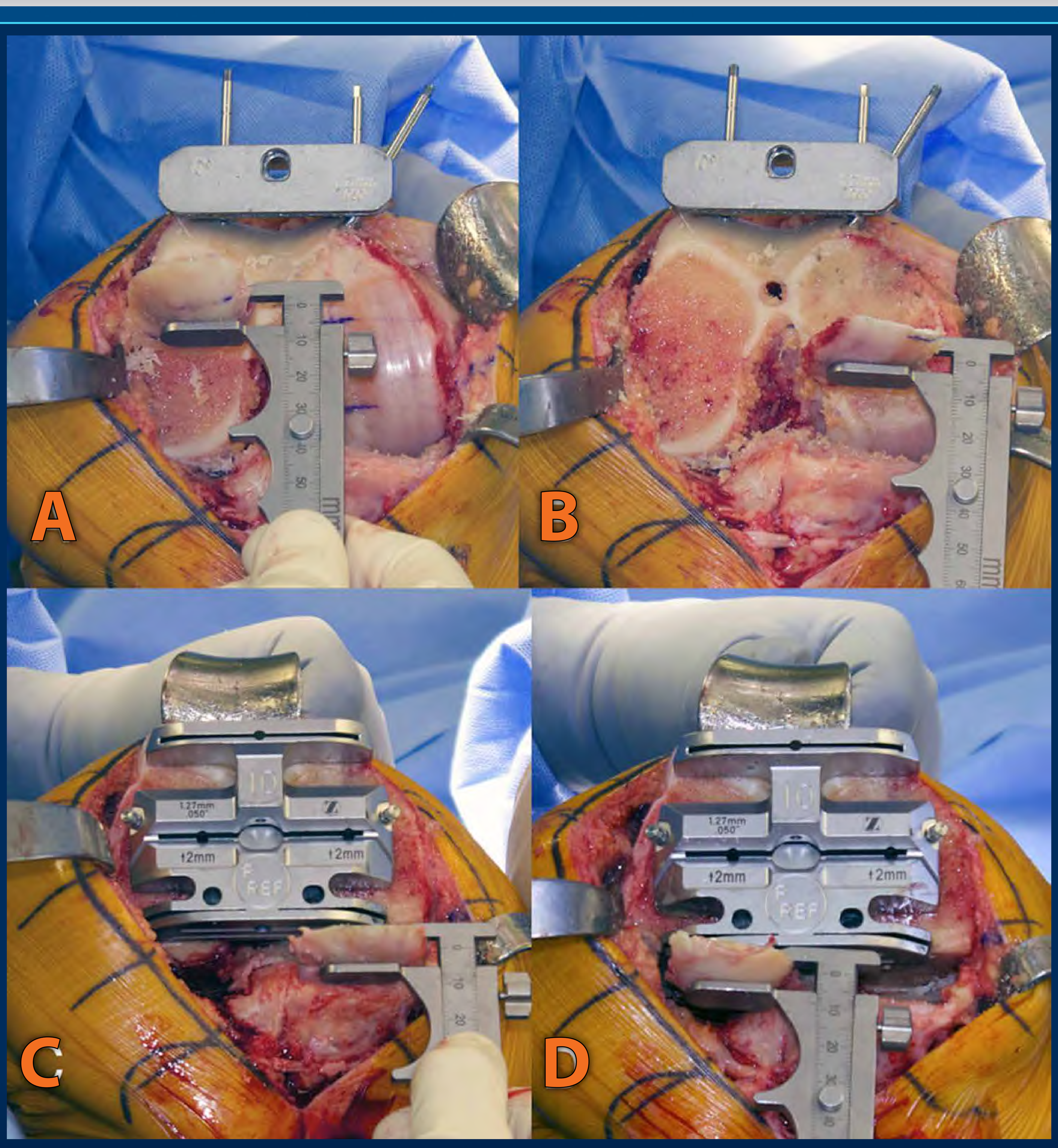

Figure 11. Composite of a right knee shows the caliper measurement of the thickness of the (A) distal lateral , (B) distal medial, (C) posterior medial, and (D) posterior lateral femoral resections. When the thickness of each resection is within ± 0.5 mm of the corresponding condyle of the femoral component after correcting for cartilage wear and kerf the femoral component is kinematically aligned[6].

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INTRAOPERATIVE CHECK FOR VERIFYING KINEMATIC ALIGNMENT OF THE TIBIAL COMPONENT

1 The intraoperative check for verifying kinematic alignment of the tibial component consists of two steps. The first step confirms the alignment of the limb in 0° of extension is natural for the patient and the V-V laxity is symmetric and negligible. When the alignment of the limb in 0° of extension appears too valgus but has a symmetric and negligible V-V laxity, the arcuate complex and popliteus tendon are released and the tibia is recut in 2° varus[6].

2 The second step confirms the offset of the anterior tibia on the distal medial femoral condyle of the trial components matches the natural offset of the osteoarthritic knee at the time of exposure (Figure 12).

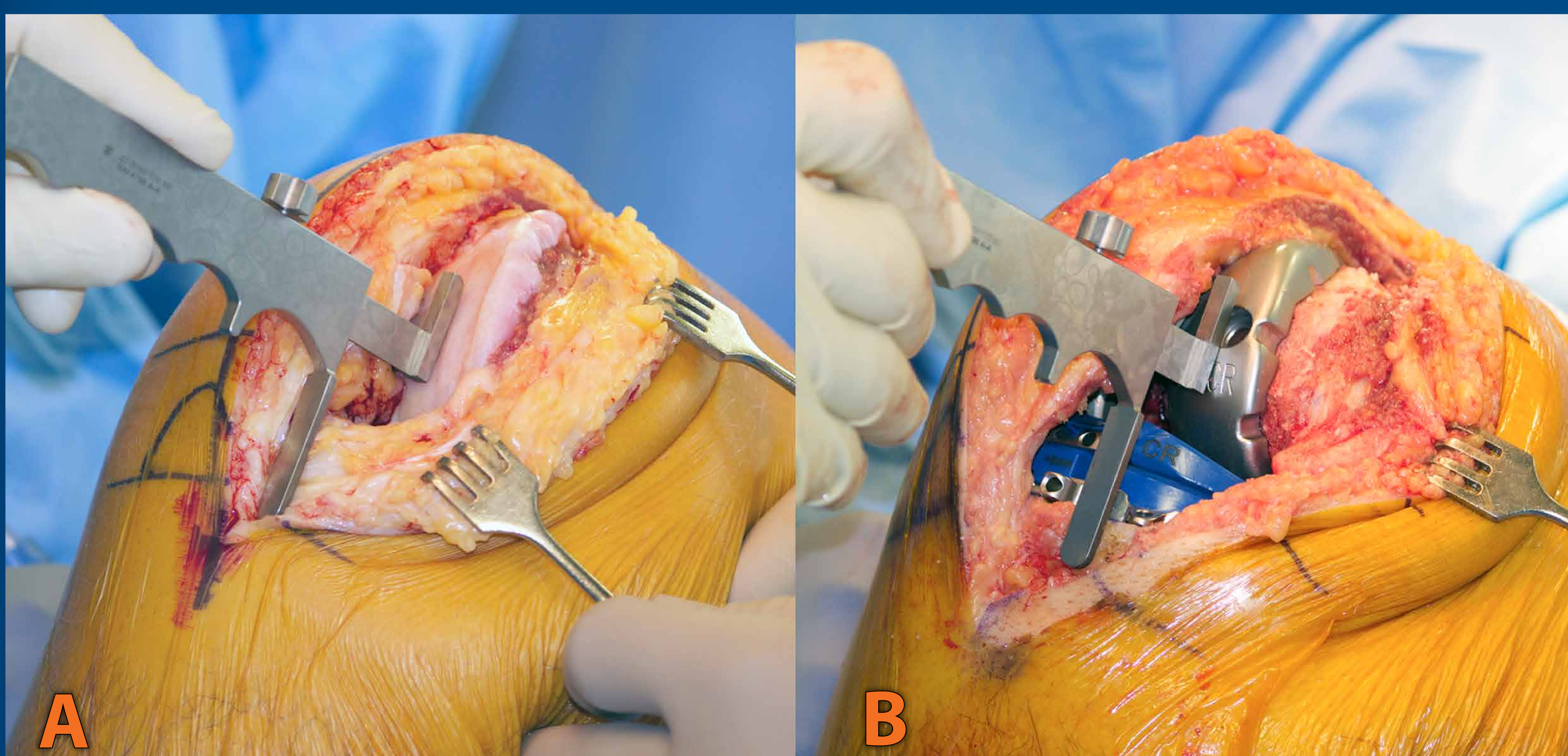

Figure 12. Composite of a right knee shows the caliper measurement of the offset of the (**A**) osteoarthritic and (**B**) reconstructed knee with trial components in 90° of flexion. The natural offset is determined at exposure by subtracting cartilage wear on the distal medial femoral condyle from the measurement. Increasing or decreasing the A-P slope of the tibial cut in 1° increments decreases or increases the offset in 1-2 mm increments[13, 14].

SIMPLE ALGORITHM FOR BALANCING THE KINEMATICALLY ALIGNED TKA

The kinematically aligned TKA is balanced by following the steps of a simple algorithm with a defined pathway and endpoint (Figure 13).

Tight in Extension & Flexion	Tight in Extension Well-Balanced in Flexion	Tight in Flexion Well-Balanced in Extension	Tight Medially & Loose Laterally in Extension	Tight Laterally & Loose Medially in Extension	Fixed Valgus
Remove more tibia	Remove posterior osteophytes Strip posterior capsule Decrease posterior tibial slope	Increase posterior tibial slope until tibial offset from femur is restored to normal at 90° flexion	Remove medial osteophytes Recut tibia in 2° more varus Use thicker liner	Remove lateral osteophytes Recut tibia in 2° more valgus Use thicker liner	Release arcuate complex and popliteus tendon Recut tibia in 2° more varus

Figure 13. The top row describes how to recognize six imbalances that require treatment. The bottom row defines the step(s) to treat each imbalance. In kinematically aligned TKA, release of a collateral, retinacular, or posterior cruciate ligament is rarely required.

STUDY 1

Kinematically Aligned TKA Restores Better Patient Satisfaction, Function, and Flexion than Mechanically Aligned TKA

INTRODUCTION

A level 1, double blind, prospective randomized controlled trial of 88 subjects was conducted to compare kinematically aligned and mechanically aligned total knee arthroplasty outcomes of pain, function and motion at two years and coronal alignment postoperatively[15].

RESULTS

Table 1. Kinematically aligned TKA restores better patient satisfaction, function, and flexion than mechanically aligned TKA and provided similar alignment the limb as mechanically aligned TKA postoperativey.

	Kinematically Aligned TKA (N = 44)	Mechanically Aligned TKA (N = 44)	Significance
Oxford (48 best)	40	33	p = 0.005
WOMAC (0 best)	15	26	p = 0.005
Flexion (deg)	121	113	p = 0.002
Postoperative Alignment of Limb (deg)	0.1 ± 2.8	-0.1 ± 2.5	p = 0.818

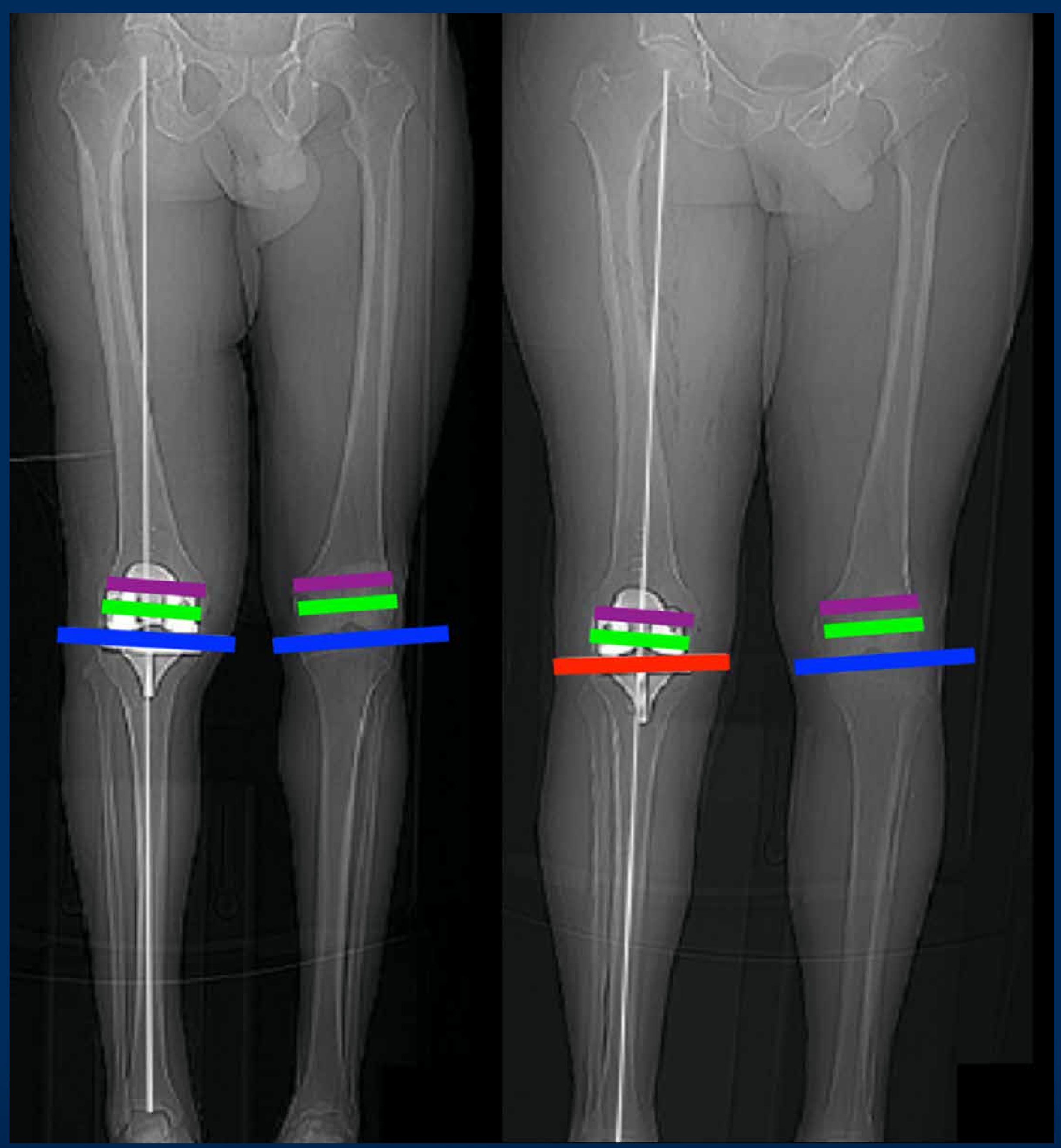

Figure 14. Composite shows that:

A. Kinematically aligned TKA restores the natural angle and level of the joint line (blue line) and aligns the flexion-extension axis of the femoral component parallel to the natural transverse kinematic axes (green and magenta lines)

B. Mechanically aligned TKA changes the natural angle and level of the joint line (red line) and aligns the flexion-extension axis of the femoral component oblique to the natural transverse kinematic axes.

Each alignment goal established a 0° mechanical axis on average (white line).

CONCLUSIONS

Kinematically aligned TKA provided better patient satisfaction, function, and flexion than mechanically aligned TKA at two years and similar alignment of the limb and knee postoperatively to that of mechanically aligned TKA.

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STUDY 2

Function and Risk of Catastrophic Failure at 3 Years Following Kinematically Aligned TKA

S. M. Howell et al, Clin Orthop Rel Res, 2012

INTRODUCTION

Kinematically aligned TKA aligns the tibial component in natural varus, which creates the concerns of early catastrophic failure and poor function[10]. This study of a case-series of 198 patients (214 knees) determined at 3 years whether the incidence of catastrophic failure and function were different when the alignments of the tibial component, knee, and limb were categorized as in-range, a varus outlier, or a valgus outlier.

RESULTS

The incidence of catastrophic failure in each alignment category was zero. Patients with an alignment categorized as an outlier and in-range had similar mean Oxford knee score at 3 years (Tables 2-4).

Table 2

	Alignment Category	Oxford knee score (48 best)	Percentage of Patients
Varus-valgus slope of tibial component	In-range (≤ 0 °)	43	25%
	Varus outlier (> 0°)	44	75%

Table 3

	Alignment Category	Oxford knee score (48 best)	Percentage of Patients
Alignment of Knee	In-range (-2.5° to -7.4°)	43	64%
	Varus outlier (> -2.5°)	45	33%
	Valgus outlier (< -7.4°)	46	3%

Table 4

	Alignment Category	Oxford knee score (48 best)	Percentage of Patients
Alignment of Limb	In-range (0 ° ± 3°)	43	73%
	Varus outlier (> 3°)	47	6%
	Valgus outlier (< -3°)	43	21%

CONCLUSIONS

The concern that kinematic alignment places the components at high risk for catastrophic failure is unfounded. This finding that varus alignment of the tibial component does not lead to catastrophic failure at 3 years should be of interest to surgeons committed to cutting the tibia perpendicular to the mechanical axis of the tibia.

STUDY 3

Are Undesirable Contact Kinematics Minimized after Kinematically Aligned TKA?

S. M. Howell et al, Knee Surg Sports Traumatol Arthrosc, 2013

INTRODUCTION

Tibiofemoral contact kinematics have a direct influence on patient function and implant longevity[16]. Undesirable patterns of contact kinematics linked to decreased patient function and implant longevity include edge loading of the tibial liner[17] and external rotation of the tibial component on the femoral component with knee flexion[18]. This study of 66 patients treated by three surgeons with kinematically aligned TKA determined whether the overall prevalence of undesirable contact kinematics between standing and mid-kneeling (90° of flexion), and between mid- and full-kneeling are minimal[19].

RESULTS

Edge loading of the tibial liner was minimal (Figure 15).

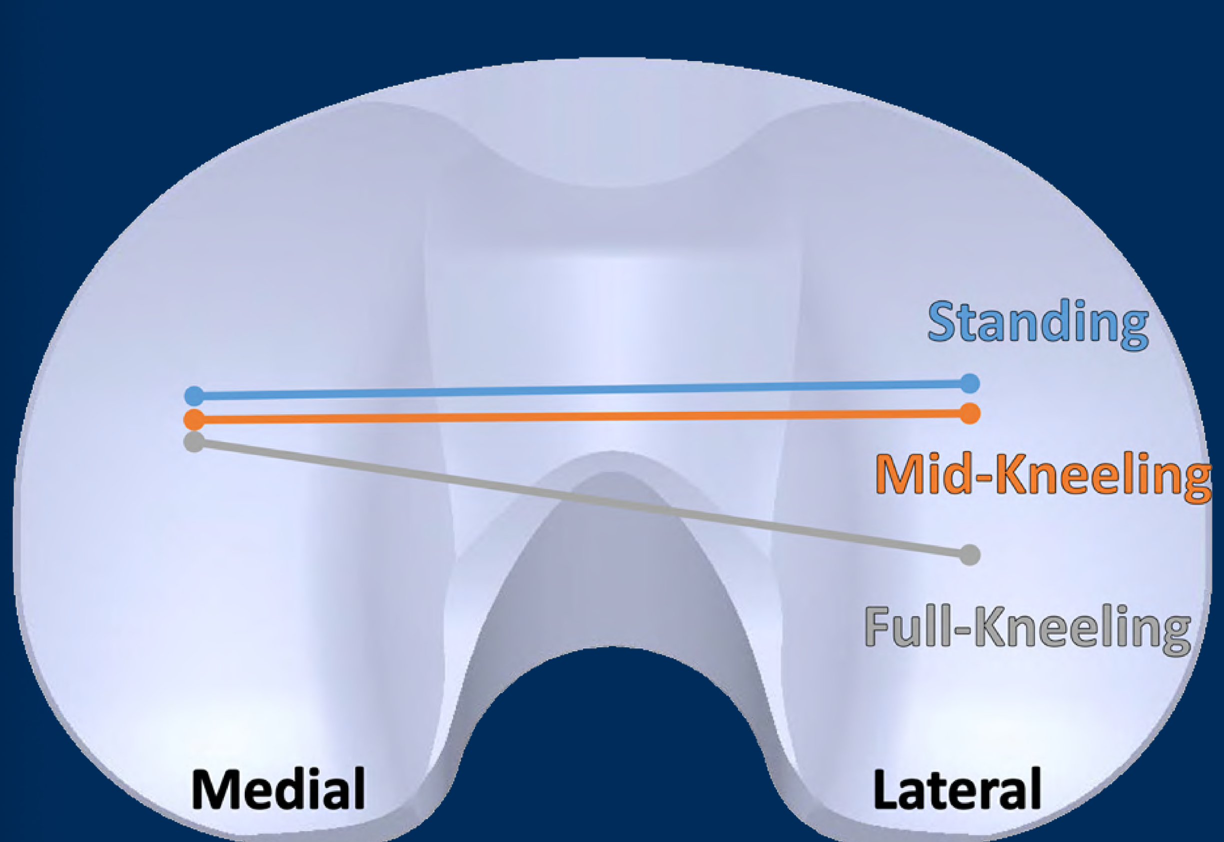

Figure 15. Proximal view of the tibial liner shows the mean A-P contact position of the femoral component on the medial and lateral tibial condyles when standing, mid-kneeling, and full-kneeling.

External rotation of the tibial component on the femoral component was minimal (Figure 16).

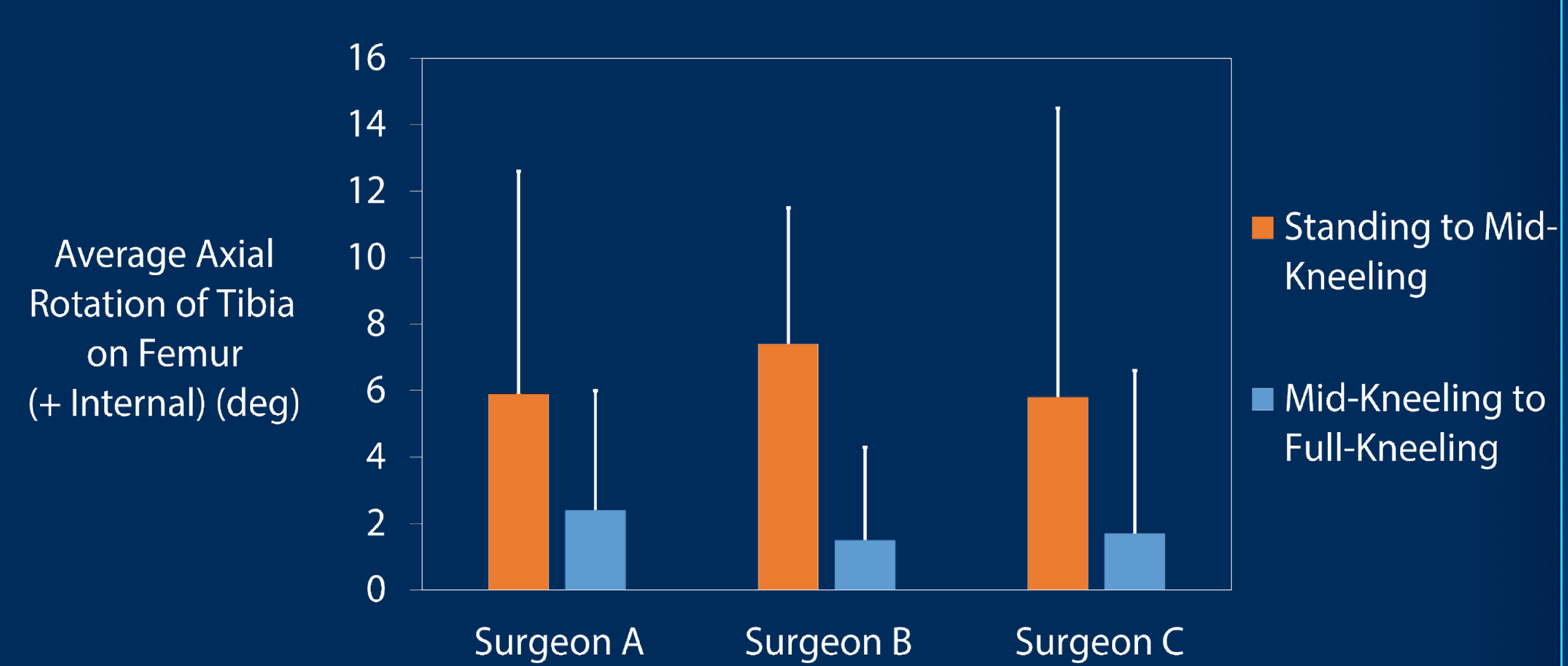

Figure 16. Column graph shows the mean and standard deviation (error bars) of the change in axial rotation of the tibial component on the femoral component from standing to mid-kneeling and mid-kneeling to full-kneeling was not different between patients grouped by surgeon. External rotation of the tibial component was rarely observed.

CONCLUSION

Kinematically aligned TKA minimizes the undesirable contact kinematics of edge loading of the tibial liner and external rotation of the tibial component on the femoral component during standing and kneeling, which suggests an optimistic prognosis for durable long-term function.

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SUMMARY OF SCIENTIFIC EXHIBIT

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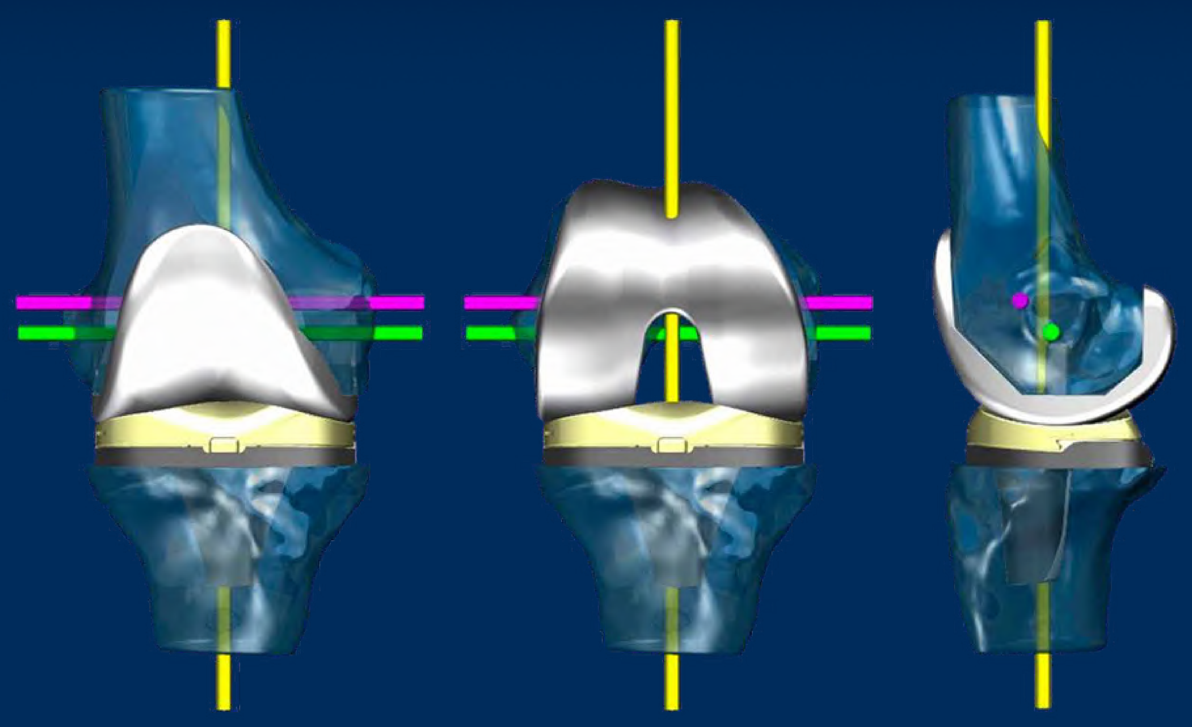
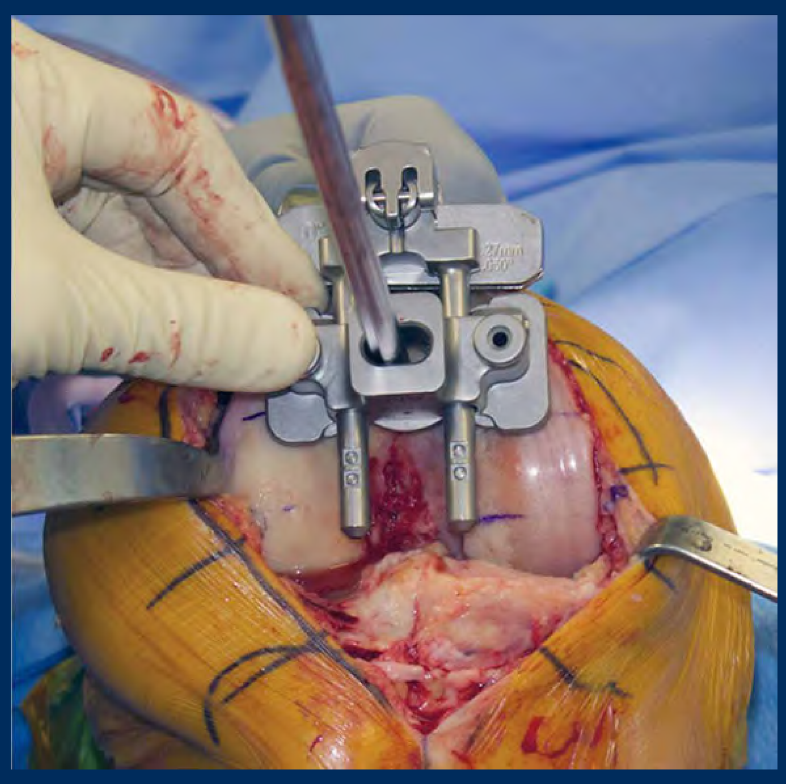
Kinematically aligned TKA positions the femoral and tibial components to resurface the articular surfaces, restore the natural angle and level of the joint lines, and minimize ligament release.



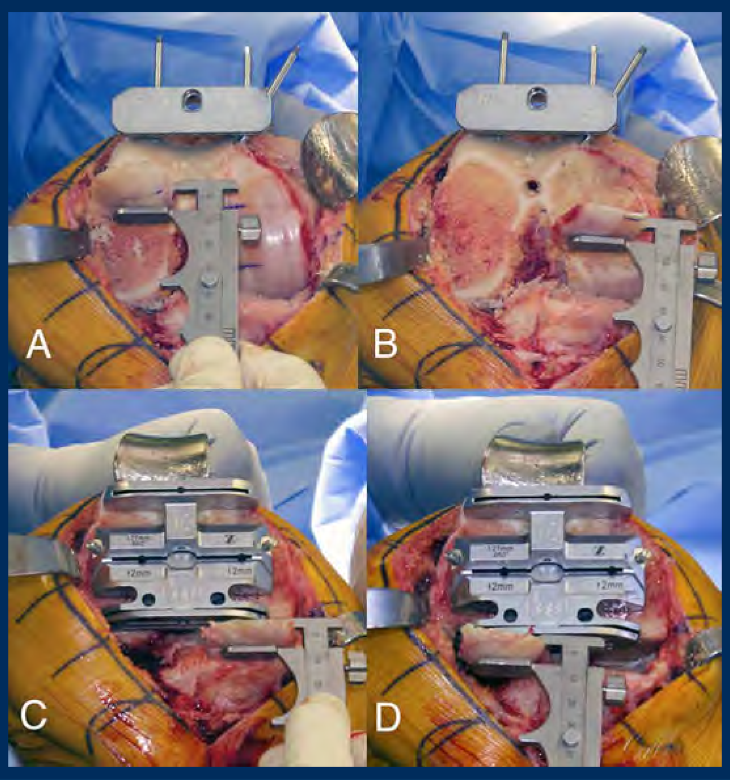
2

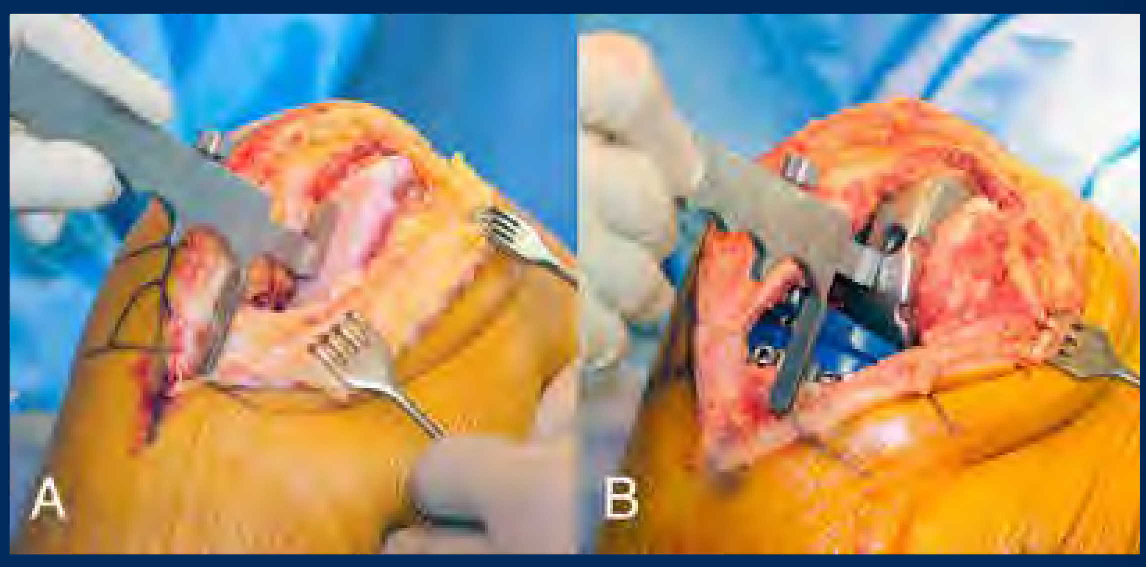
The generic instruments used for kinematically aligned TKA are similar in design and identical in function to the instruments approved by the FDA and introduced by Hungerford et al[8].



3

Two intraoperative checks that verify kinematic alignment of the femoral and tibial components with generic instruments enable the use of a simple step-wise algorithm for balancing the kinematically aligned TKA minimizing ligament release.





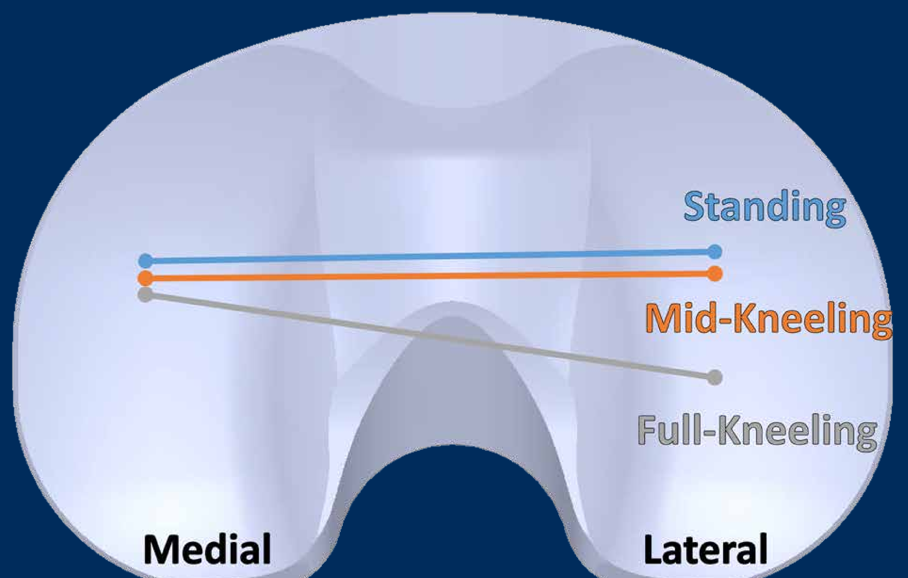
4

Kinematically aligned TKA restores better function and flexion than mechanically aligned TKA at two years and leads to similar alignment of the limb and knee postoperatively.

	Kinematically Aligned TKA (N = 44)	Mechanically Aligned TKA (N = 44)
Oxford (48 best)	40	33
WOMAC (0 best)	15	26
Flexion (deg)	121	113
Postoperative Alignment of Limb (deg)	0.1 ± 2.8	-0.1 ± 2.5

5

Minimizing undesirable contact kinematics explains the absence of catastrophic failure of the kinematically aligned TKA at 3 years.



We hope this scientific exhibit will encourage surgeons to consider kinematic alignment when performing TKA.

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