Arthroplasty Today 8 (2021) 157–162

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original research

Measured Resection Techniques Do Not Align to the Cylindrical Axis in Kinematic Total Knee Arthroplasty

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ARTICLE INFO

Article history:
Received 9 September 2020
Received in revised form
16 February 2021
Accepted 23 February 2021
Available online xxx

Keywords:
Kinematic alignment
Caliper resection
Patient specific instrumentation
Cylindrical axis
Hip knee ankle angle
Total knee arthroplasty

ABSTRACT

Background: There has been increasing interest with improved functional results in kinematically aligned total knee arthroplasty. Kinematic alignment seeks to replicate the rotational axes of the individual knee. The femoral component can either be aligned to the estimated prearthritic distal and posterior joint lines via a measured-resection technique or by aligning to the cylindrical axis (CA). The CA is calculated using three-dimensional imaging and defined as a line equidistant from the medial and lateral condylar surfaces from 15° to 115° flexion. This study investigates whether these 2 techniques lead to similar alignment angles in the coronal plane.
Materials and Methods: One hundred three knees undergoing total knee arthroplasty were assessed using a computed tomography-based protocol. The image-based cylindrical axis coronal angle (CAA) was calculated, and the distal condylar coronal angle (DCA) was calculated to simulate a caliper measured resection technique. A computed tomographic planning software program was used to measure the offset from the distal-most extent of the calculated cylinder to the distal-most aspect of the condyles.
Results: The DCA measured 3.3° valgus (standard deviation 2.4°) and the CAA 1.8° valgus (standard deviation 2.1°). The mean difference in offset from CAA radius to DCA from the medial condyle and the lateral condyle was 2.85 mm and 1.51 mm, respectively, increasing valgus predilection.
Conclusions: Caliper measured resection kinematically aligned techniques will position the femoral component in a significantly more valgus position than when aligning to the CA of the knee. This is due to an increased offset of the distal femoral articulation from the most distal aspect of the cylinder on the medial side of the knee.

Introduction

There is increasing interest in kinematically aligned (KA) total knee arthroplasty (TKA) as surgeons seek to increase patient satisfaction, function, and flexion [1–5]. The goal of KA TKA is to restore native alignment of the limb, rotational axes, and joint lines without soft tissue release [6]. Kinematic alignment can be performed using multiple methods to restore alignment and balance to the 3 kinematic axes: the axis in which the patella articulates, the axis of tibial rotation axially with the femur, and the flexion-extension axis of the tibia around the femoral condyles [7,8]. This alignment methodology does not assume a standard femoral valgus or extra-articular landmarks, such as epicondyles, to align rotation, and KA restores the normal patient specific anatomy and improves patient outcomes including Knee Society Scores [5,9]. With KA alignment resecting only what will be replaced with the prosthesis, after assuming cartilage and bone loss, the native joint kinematics are restored, compared with mechanical alignment angle assumptions, releases, and rotational changes to obtain a balanced knee.

Eduard and Wihelm Webber in 1836 described a constant radius of curvature of the surfaces of the femoral condyles in the sagittal plane from 10-160 degrees, that was confirmed by Elias et al. in cadaveric specimens [10–12]. Figure 1 Eckhoff et al. and others

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https://doi.org/10.1016/j.artd.2021.02.014

demonstrated with radiographic computed tomographic (CT) analysis that the medial and lateral condyles demonstrate an equal symmetrical radius of curvature [12–14]. The 2 centers of curvature of the femoral condyles can be joined to form the cylindrical axis (CA) of the femur, the true flexion extension axis of the tibia about the femur. The femoral component of the TKA is to be aligned to this axis in KA, restoring this native movement [15].

Alternatively, a caliper measured resection technique can be used to kinematically align the femoral component, without the use of three-dimensional CT analysis [15,16]. The caliper measured resection method for femoral alignment in KA TKA involves referencing the distal-most and posterior points on each condyle with corrections for cartilage loss [4,15–17]. This technique uses manual instrumentation, without the need for preoperative three-dimensional imaging. Several authors have shown that the measured-resection caliper method accurately restores native knee alignment [15,18–20]. Howell et al. found in 10-year follow-up that KA TKA has a low revision rate with no increase in varus tibial implant failure [3,21].

Recently Nedopil et al. have shown in a series of 36 patients caliper resection kinematic alignment does not lead to increased valgus alignment with no change to oxford knee or forgotten knee scores when compared with contralateral knees [22].

This study aims to assess whether caliper measured resection alignment technique is different to CA alignment in the coronal plane and locate the cause of the alignment difference between the 2 techniques. We hypothesize that owing to the radius of femoral curvature not matching the articular surface over the flexion arc from 0-15 degrees, the 2 techniques will yield different results in coronal alignment.

Material and Methods

Between December 2015 and March 2018, 91 consecutive patients awaiting KA TKA underwent a preoperative CT scan for patient-specific instrumentation using the Medacta MyKnee protocol (Castel San Pietro, Switzerland). The time period was chosen to align with database data collection in this Australian single-surgeon practice. This imaging included the hip and knee and rendered a 3D reconstruction of the distal femur, allowing for calculation of the mechanical axis, the CA, and the distal condylar geometry. The CT scan with rotational parameters and ability to 3D print patient specific guides is a standard workup for the MyKnee program. The scans allowed the KA to be calculated, posterior condylar axis (PCA), cylindrical axis coronal angle (CAA), and the dimensions of the distal femur. The KA and planning were performed by a single engineer in the MyKnee program set for the senior author, as part of the support service from Medacta.

Calculations were performed by a single engineer using a protocol similar to that in the original work by Eckhoff et al. [14] to determine the CA using circles of best fit over the bone of the medial and lateral condyles over the arc of flexion between 15 and 115 degree, ensuring that the most posterior point of the condyles was included. The CAA was determined by measuring the coronal component of the CA relative to the perpendicular to the mechanical axis of the femur. Patient demographics were not included in the analysis as CT-based assessment for alignment and deemed not to greatly impact the change in distal condylar axis to CA.

The angle of the measured-resection KA cuts was simulated by determining the 2 most distal bony points of the medial and lateral condyle in the same plane as the femoral shaft. These points equate to those referenced by the surgeon to calculate the calipered resection depths. The line joining these points was used to determine the distal condylar coronal angle (DCA), which was defined relative to the perpendicular to the mechanical axis. Figure 1 We have assumed minimal bone loss as 99.5% of knees have less than 1 mm of bone loss in extension and flexion in the arthritic femur [23].

The protocol followed a reference plane to the mechanical axis, with valgus being positive, with the calculated angle referenced to the perpendicular to the mechanical axis. A 3D workstation was used to measure the offset of the most distal aspect of the femoral condyle to the most distal limit of the calculated cylinder. The CT imaging allowed a condylar axis reference to be applied using the Medacta MyKnee (Medacta, Castel San Pietro, Switzerland) program with manual best circular fit between 15 and 140 degrees of flexion. Each knee circle of best fit had the same radius of curvature between the lateral and medial condyles. The difference between the distal condylar assessment and the circle of best fit would demonstrate the difference measured in caliper resection for the distal condylar axis and the CA (Figure 2).

Statistical analysis was performed with assistance of Prism (Graphpad, La Jolla, CA). Statistical significance was set at *P* value of <.05, and we aimed to detect a greater than 1° difference in CAA to DCA. Using the prior work by Niki et al., a power analysis required greater than 25 knees [24].

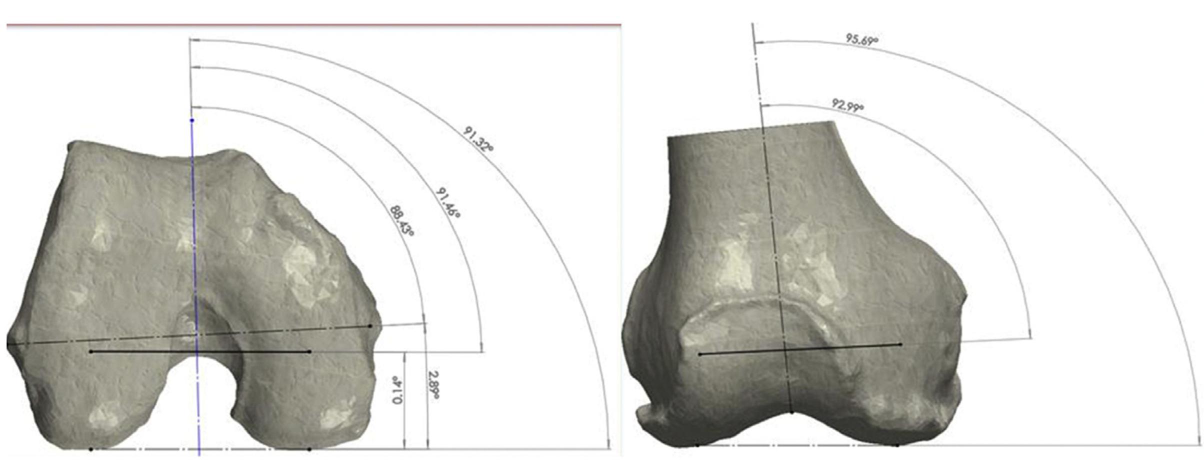

Figure 1. Three-dimensional reconstruction of knee model. left, Axial rotation planning of the posterior condylar axis and flexion extension axis. Right, coronal view displaying the flexion extension axis of the knee relative to mechanical and distal condylar axis, Valgus is positive. Right knee model.

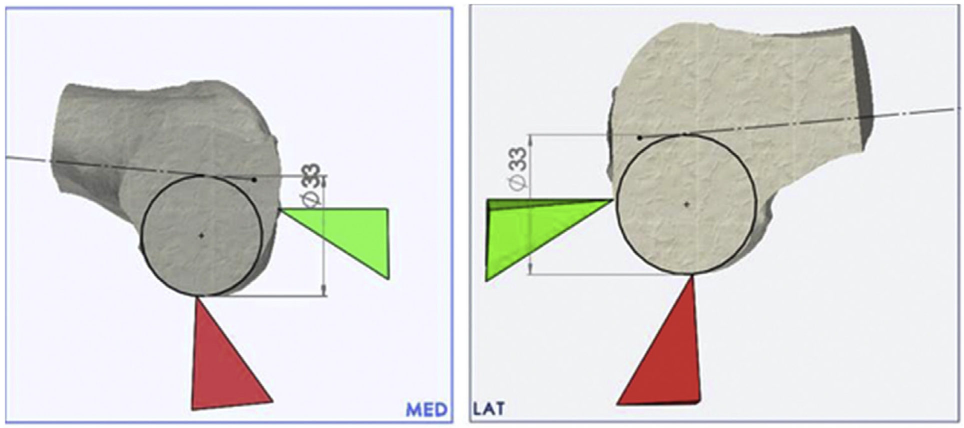

Figure 2. Two-dimensional representation of cylindrical axis (CA) and reference point for distal condylar axis (DCA). The offset is the distance from the radius of the cylindrical axis to distal most point of the femur, in the anatomic plane. The change in offset between the medial and lateral condyles leading to altered DCA to CA coronal angle (CAA) is shown.

Results

One hundred and three total knee plans were compared for 53 females and 38 males; 7 males had staged bilateral knees within the study period. Preoperative alignment determined by CT modeling of the 103 knees recorded 6 neutral, 83 (80.6%) varus, and 14 (13.6%) valgus. See Table 1. Seventeen cases were not included in the "offset measurement" analysis as only the angular data were available, leaving 86 knees for DCA offset analysis. Figure 3 displays the correlation of the angular discrepancy between the CAA and DCA and offset between the medial and lateral condyles from the CAA and radius of curvature, with the lateral offset having a negative correlation to the CAA. The increased valgus alignment of the CAA, the closer the distal lateral condyle offset matches the CAA, as seen in Figure 4.

The results demonstrate a significant difference, ($P < .001$), between the distal condylar coronal angle (DCA) and the CAA, with the DCA overestimating the valgus by a mean of 1.39^{o} and a mean offset of 1.34 mm from the expected medial and lateral condylar radius of curvature. A statistically significant valgus predilection of the distal condylar axis referencing is evident with the increased medial condyle predicted resection in all but 7 knees, 8.5% of 86 knees. Increased medial and lateral distal condyle estimated resection in 72 (83%) and equal in 7 knees (8.5%).

The DCA was 4.48° (−3.28 to 8.25°), whereas the CAA was 3.06° (−5.5° to 6.83°) for all knees. This statistically significant difference ($P < .001$) is due to the variation in offset of the distal condylar surface from the CAA radius of curvature, and we defined this variation as the offset. The offset is different between the medial and lateral condyles in all but 8.5% of knees in this series. The mean offset of the medial femoral condyle is 2.85 mm and 1.51 for the lateral. This disparity between medial and lateral offset is the cause of altered DCA to CAA. Table 2 demonstrates the change in the DCA, and a function of the MFC and LFC offset is different for 91.5% of knees to the CAA, a mean of 1.34 mm, and is more evident in valgus knees, with both statistically significant ($P < .001$).

We found that this difference was manifested via a change in the lateral offset, with the medial offset remaining relatively constant between varus and valgus subgroups. The valgus knee mean lateral condylar offset was 1.19 mm (0-2.5 mm) compared with varus knees with an offset of 1.57 mm (0-5 mm) ($P = .034$). The medial femoral condyle offset in varus and valgus aligned knees remained constant at 2.85 mm (0-5.5) and 2.84 mm [1–4], respectively.

Table 1
Patient alignment demographics.

Patients	91
Knees	103 (52 Right, 51 Left)
Males	38 (45 knees)
Female	53 (58 knees)
Alignment	
Varus	83 (Mean, 5.5°, Max 15°)
Neutral	6
Valgus	14 (Mean 2.8°, Max 8°)

Discussion

KA TKA, whether it be via measured resection, navigation, or using patient specific instrumentation, shows a greater than or equal patient satisfaction, recovery, and function to mechanical alignment [9,15,19,25–27]. The aim of this analysis was to assess if the alignment created by a caliper-measured resection KA femoral component was similar to an imaged-based CA calculation. The primary finding of this study is that the measured resection technique will position the femoral component in more valgus deviation than one aligned with the cylindrical condylar axis, the true flexion extension axis. This tendency is greater in patients with valgus preoperative alignment. Drawing on prior work regarding kinematic alignment and the valgus predilection, we have determined the location for this error and how to improve the alignment through the CA [22].

Using the distal condylar measured resection for FEA increased the valgus alignment and may be a possible cause for the trend of kinematic alignment to mild valgus [3,15,19,22]. A significant concern with increasing femoral component valgus is that to balance the ligaments of the knee, the tibial component will need to be placed in increased compensatory varus. Fortunately, varus tibial collapse has not been shown in the study by Howell et al., in the 6- and 10-year follow-up of kinematic alignment knees, or in the review of methods of failure in kinematic knees by Nedopil et al. [3,21,28]. Johnston et al. showed that varus tibial components have a lower wear rate than ideal alignment in a biomechanical study using the DePuy Sigma knee [29]. Clinically this difference in alignment of less than 2 degrees is not significant in Forgotten Knee Score or Oxford Knee Score at 20 months [22]. Although not shown in functional scores to be of concern to date, the measured resection does have inbuilt error leading to increased valgus alignment in our study.

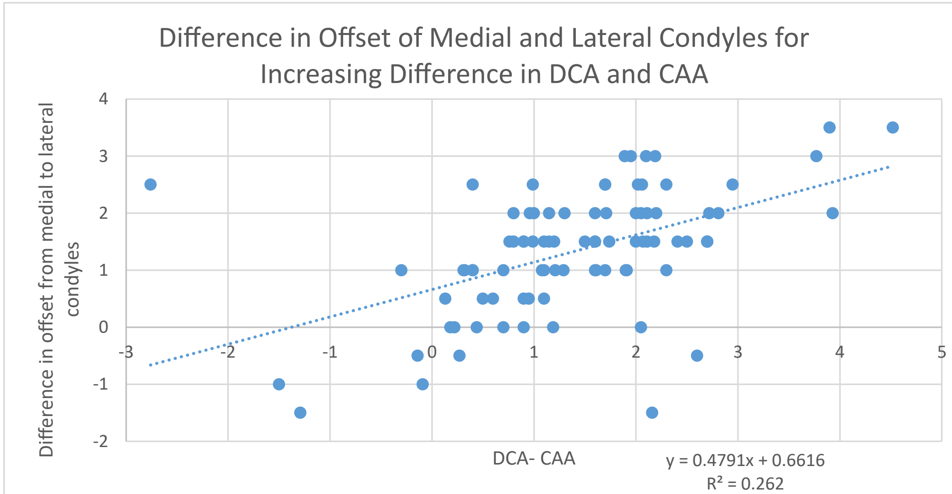

Figure 3. Correlation graph comparing the difference between the DCA and CAA and the difference between the medial and lateral condylar offset (*P* value < .001).

Our results have shown the discrepancy between the CAA and DCA is due to a variation in the distance between the CA and the distal femoral articulation, which is greater on the medial condyle than on the lateral in 83% of knees. While our study supported the finding of a constant radius of curvature from 15-115 degrees of flexion, the morphology of the distal femoral articulation on the

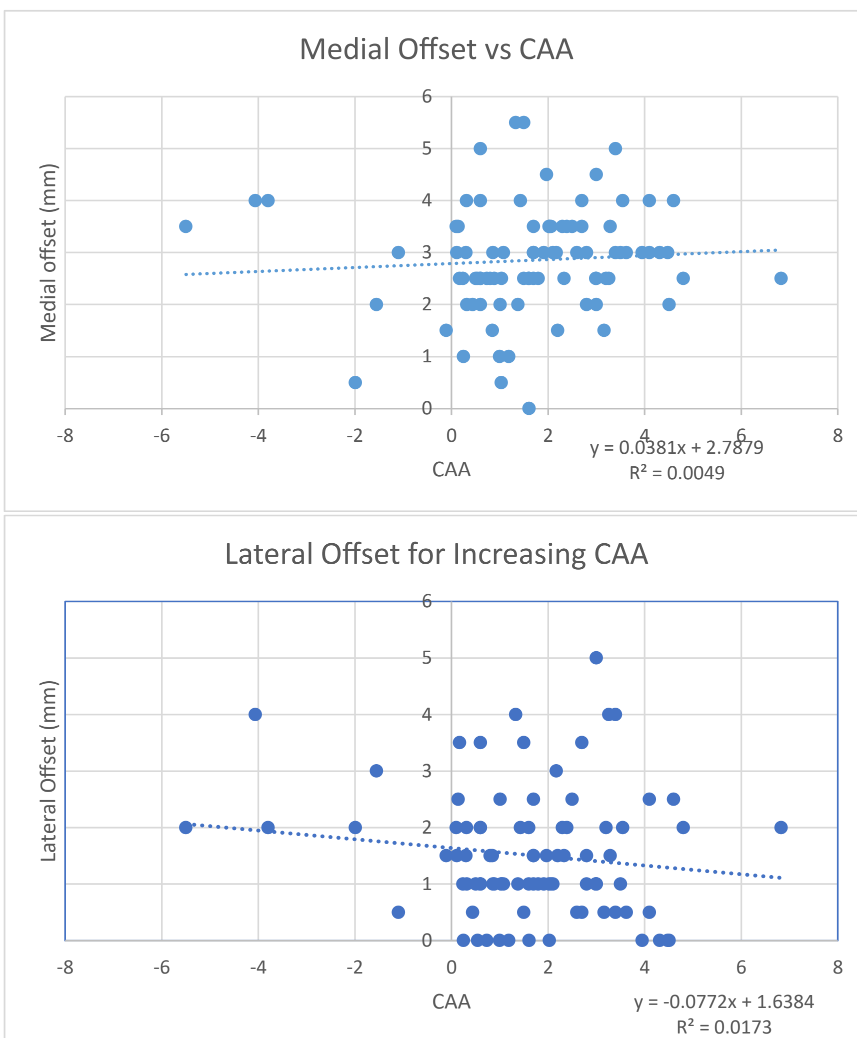

Figure 4. Medial and lateral offset vs CAA. Top: Medial offset vs CAA, showing a relatively horizontal line, with a relatively constant offset independent of CAA. Bottom: Lateral offset vs CAA, displaying a trend toward decreasing lateral offset as the CAA increases (valgus alignment).

Table 2
Coronal alignment comparison distal condylar axis to cylindrical cylinder axis, all knees, varus, and valgus subsets.

Preoperative alignment					
	All knees (°)	Varus (°)	Valgus (°)	*P* value	Range (°)
HKA	175.9 (4.1°)	174.5 (5.5°)	182.8 (2.8°)		165 to 188 (−15° to 8°)
L DFA	3.3	3	4.7	.0141	0 to 8.0
M PTA	3.6	3.8	2.2	.0053	0 to 8.5
Bony HKA	−0.3	−0.8	2.5		−7.5 to 6.5
Cartilage wear change HKA	3.8 varus	4.7 varus	0.3 valgus	<.001	
DCA and CAA analysis					
DCA	4.48	4.17	6.43	<.001	−4.28 to 8.25
CAA	3.06	2.8	4.72	<.001	−4.5 to 12
Difference between DCA and CAA	−1.39	−1.37	−1.71		
	P value <.001	*P* value < .0001	*P* value = .0001		
Measured condylar offset					
LFC	1.51	1.57	1.19	.034	(0 to 5mm)
MFC	2.85	2.85	2.84		(0 to 5.5mm)
Difference in offset	1.34 mm	1.28 mm	1.65 mm	.78	
P value	<.0001	<.0001	<.0001		

CAA, cylindrical axis coronal angle; DCA, distal condylar axis; HKA, hip-knee-ankle angle; L DFA, lateral distal femoral angle; LFC, lateral femoral condyle offset; MFC, medial femoral condyle offset; M PTA, medial proximal tibial angle.

extension surface varied significantly from the cylinder of best fit. The distal femoral condylar surface anatomy led to variable offset from the medial and lateral femoral condyle CAA reference. There was a mean difference of 1.34 mm increased offset between the distal medial and lateral femoral condyles. This was more evident in valgus alignment knees, with 1.65 mm increased offset, which further increased the difference between the CAA and the DCA to 1.71 degrees. Our study confirms this is the source of the error between measured resection and CAA assessment of the flexion extension axis of the knee.

This statistically significant difference between the distal condylar axis with CAA leads to an increase in the valgus alignment of the femoral component of approximately 1.39°. This is more evident in valgus knees; DCA average 1.7 degrees valgus to CAA. The KA techniques assess overall alignment but change with millimetre accurate resection intraoperatively, allowing an error of approximately 1 mm accepted. This increase in valgus alignment equates to an average of 1.34 mm, all knees, and 1.65 mm in valgus knees imbalance between flexion and extension through the lateral compartment. We agree with prior research stating no clinical difference in the short term but would attempt to decrease the error of the caliper method with knowledge of the limitations of the distal condylar axis, particularly in valgus aligned knees. Studies have shown 88% of measured resection KA TKA are within 2° of the contralateral limb, with no clinical difference compared with those out to 3° off desired alignment [22]. The CA uses multiple points for the arc of best fit between 15° and 115°, resulting in less error than single distal condylar reference points. Our results of a large population demonstrate a more reliable, reproducible, and minimized error using the CAA for kinematic knee alignment over the distal condylar axis and will await to see in longer large studies if this has a clinical impact.

The limitations to this analysis include the simulated referencing of the measured-resection points, which would potentially be altered by the positioning of the intramedullary rod. In addition, our preoperative alignment hip-knee-ankle angles were calculated using CT modeling, rather than standing long leg radiographs, using similar methodology to Niki et al. [24]. Future studies may correlate this predicted DCA with intraoperative measurements of actual measured resection KA cuts. Our calculations are based on CT measurements and do not account cartilage variations within and between condyles or operative estimates and changes made by experienced surgeons with measured resection techniques. The CA was determined by a single engineer using a mathematical assessment of best fit circle for the condyles. This may have small anatomic errors, but the circle of best fit uses multiple data points to determine the center, thus decreasing the error. Although no intraobserver or interobserver reliability was performed, we believe the results are still valid through the accurate reproducible measurement methodology and valid in the conclusion. Our single-center cohort had relatively small numbers of preoperative valgus aligned arthritic knees, but all numbers reached significance and displayed a consistently increased valgus alignment of the DCA to the CAA. We must acknowledge the senior author receives financial support from Medacta, but we believe this does not detract from the overall message of measured caliper-based resection increases valgus alignment to the CA.

Conclusions

The caliper measured resection technique for kinematic alignment of the femoral component positions the femoral component in a more valgus position than when it is aligned to the CA. The improved kinematic alignment using the CA improves alignment thus possibly function and satisfaction.

Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The senior author, B.B. receives indirectly fellowship funding from Medacta and is a paid speaker for Medacta, Arthrex, and Smith and Nephew. These were not considered or used with this article.

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