Original Article

A Best-Fit of an Anatomic Tibial Baseplate Closely Parallels the Flexion-Extension Plane and Covers a High Percentage of the Proximal Tibia

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Abstract

There are no reports of in vivo internal–external (I–E) rotational alignment and coverage of the proximal tibia after performing a best-fit method of an anatomically designed and asymmetrically shaped tibial baseplate during calipered kinematically aligned (KA) total knee arthroplasty (TKA). We hypothesized that a best-fit plane sets the anterior–posterior (A–P) axis of the anatomic baseplate closely parallel to the flexion–extension (F–E) plane of the knee and covers a high percentage of the proximal tibia. A total of 145 consecutive primary TKAs were prospectively collected. The calipered KA method and verification checks set the positions and orientations of the components without ligament release in all knees without restrictions on the preoperative deformities. A best-fit method selected one of six trials of anatomic baseplates that maximized coverage and set I–E rotation parallel to and within the cortical edge of the proximal tibia. The angle between the transverse axes of the components (i.e., the deviation of the A–P axis of the anatomic baseplate from the F–E plane of the native knee) and the cross-sectional area (CSA) of the proximal tibia were measured on postoperative computerized tomographic scans. The mean deviation of the anatomic baseplate from the F–E plane was 2-degree external ± 5 degrees. The mean coverage of the proximal tibia was 87 ± 6% (CSA of baseplate from the manufacturer/CSA of proximal tibia × 100). The anatomic baseplate and best-fit method adequately set I–E rotation of the baseplate closely parallel to the F–E plane of the knee and cover a high percentage of the proximal tibia.

Keywords
- knee arthroplasty
- tibial component
- kinematic alignment
- flexion–extension plane

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Correct internal–external (I–E) positioning of the femoral and tibial components is essential for successful total knee arthroplasty (TKA). In mechanically aligned (MA) TKA, the risks of pain, poor satisfaction, and low function are greater when the difference in I–E rotational between the antero-posterior (A–P) axes of the tibial baseplate and femoral component is >10 degrees.[1–3]

Calipered kinematically aligned (KA) TKA, which sets components coincident to the native or prearthritic joint lines without ligament release, is gaining momentum because of multiple reports of favorable results (►**Fig. 1**). Seven randomized or case-control studies comparing KA TKA to MA TKA reported better results in the KA TKA cohort in terms of patient satisfaction, function, speed of recovery, soft tissue balance, flexion, and the orientation of the components during weight bearing in single-leg stance.[4–10] Two other randomized control studies reported similar tibial component migration at 2 years[11] and similar clinical outcomes between the KA and MA TKA cohorts[12]. A difference in alignment explains the better results obtained with KA,[5–8] as the calipered technique accurately restores the native joint lines and *q*-angle that affects patellofemoral tracking.[13] Whereas MA alters the native distal femoral and proximal tibial joint lines greater than $\pm$ 1.5 degrees in 84 and 70% of patients,[14,15] and changes the *q*-angle.[16]

KA strives to rotationally align the A–P axis of the tibial baseplate parallel to the F–E plane of the native knee,[17–19] which is different from the MA targets of the medial one-third, medial one-sixth, and medial border of the tibial tubercle.[20–24] Anatomically, the orientation of the F–E plane is perpendicular to the distal and posterior joint lines of the native femur (►**Fig. 2**).[19,25] The calipered KA technique accurately sets the A–P axis of the femoral component within a negligible mean deviation of 0.3 ± 1.1 degrees of external from the F–E plane and reliably coaligns the F–E axis of the femoral component to that of the native knee [18,26]. Adjustment of the thicknesses of the distal and posterior femoral resections after compensating for wear and the kerf of the saw blade to within 0 ± 0.5 mm condyles of the femoral component achieves this level of reproducibility.[13,18,26,27] Therefore, the proxy for the deviation of the A–P axis of the anatomic baseplate from the F–E plane is the angle between the transverse axes of the femoral and tibial components (►**Fig. 3**).[17–19,28]

Whether to use an anatomically designed and asymmetrically shaped tibial baseplate with KA and MA is controversial. Several studies of MA TKA favor the use of a best-fit plane of an anatomic baseplate because of higher coverage of the proximal tibia, especially in the posteromedial tibia, and a lower risk of malrotation when compared with symmetric baseplates.[20,22,29]

As there are no reports of the use of an anatomically designed tibial baseplate with calipered KA TKA, we hypothesized that a best-fit plane sets the A–P axis of the anatomic baseplate closely parallel to the F–E plane of the knee and covers a high percentage of the proximal tibia.

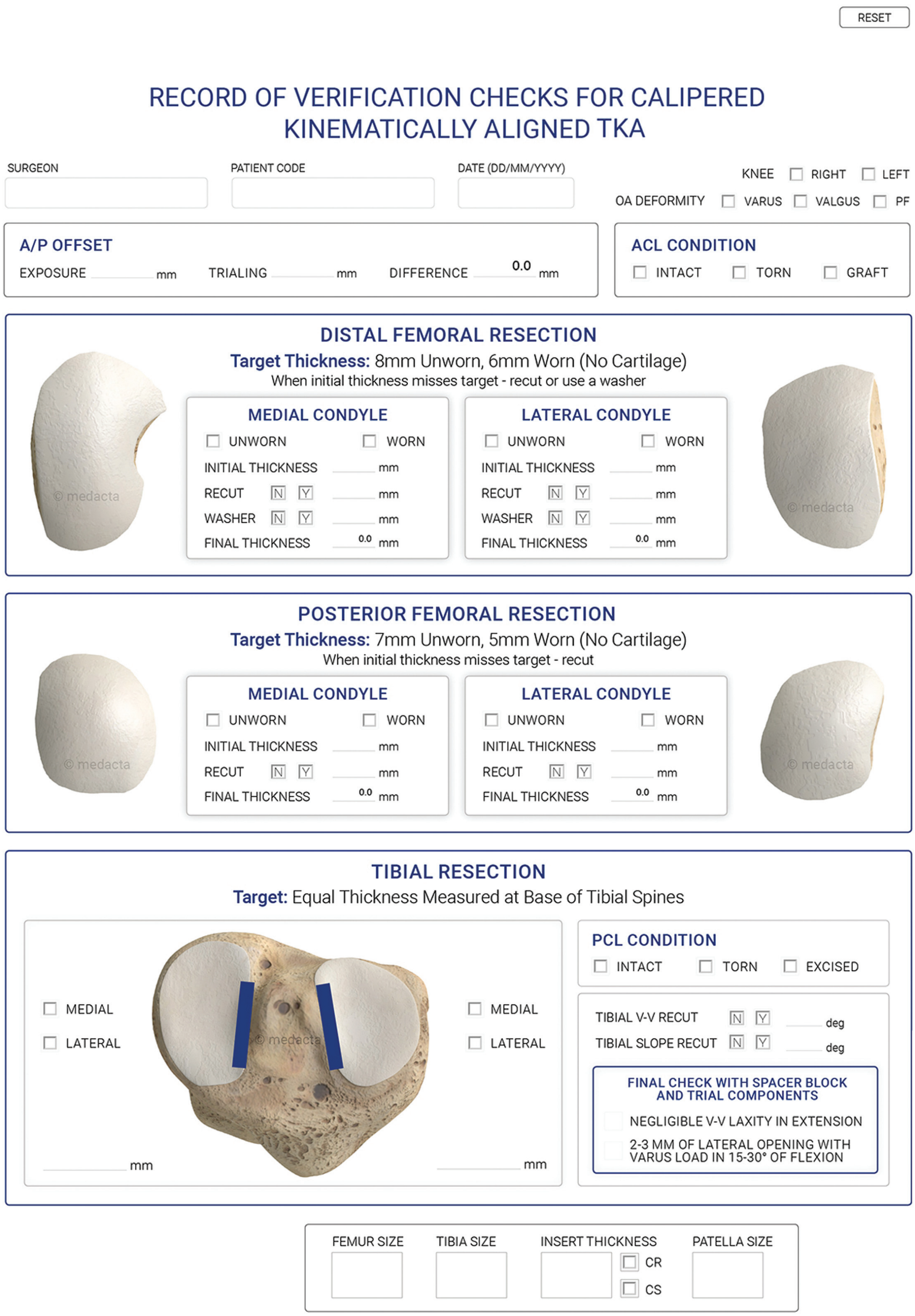
Patients and Methods

An institutional review board (IRB) approved this retrospective study of patients (IRB: 1450373–1). From November 2018 through January 2019, 146 consecutive primary cemented TKAs were performed with calipered KA with use of manual instruments and verification checks.[9,10] A posterior cruciate ligament retaining femoral component with a spherical medial femoral condyle, an anatomic tibial baseplate, a fixed-bearing tibial insert with a medial ball and socket and a flat lateral surface, and an anatomic patella component were used (Sphere GMK, Medacta Inc, Castel San Pietro, CH). The indications for TKA included disabling symptoms that had not resolved after conservative knee treatment, radiographic evidence of Kellgren–Lawrence grades 2 to 4 arthritic changes or osteonecrosis, any severity of flexion, varus, and valgus deformity as measured when non–weight bearing with a goniometer. Preoperatively, each patient completed the Oxford Knee Score (OKS; 48, best and 0, worst) for the knee scheduled for treatment.

A single surgeon (S.M.H.) performed the calipered KA TKA using manual instruments through a midvastus approach and intraoperatively recorded a series of verification checks using a previously described technique (►**Fig. 1**).[30,31] For the femoral component, the I–E and varus–valgus (V–V) rotations and the A–P and proximal–distal (P–D) positions were set coincident with the native distal and posterior joint lines by adjusting the calipered thicknesses of the distal and posterior femoral resections to within 0 ± 0.5 mm of those of the femoral component condyles after compensating for cartilage wear and kerf of the saw blade. These steps set the femoral component with a bias of 0.3 degrees and precision of $\pm$ 1.1 degrees with respect to the F–E plane of the knee and reliably aligned the cylindrical axis of femoral component to the F–E axis of the native knee.[18,26]

The knee was balanced by adjusting the P–D resection thickness, V–V angle, and slope of the plane of the proximal tibia with use of verification checks, which restores the native tibial joint line.[13,32] The V–V rotation was set using the following two verification checks. The thicknesses of the medial and lateral proximal tibias were measured at the base of the tibial spines with a caliper and adjusted for equality to within 0 ± 0.5 mm. The landmark of the unworn base of the tibial spine has several advantages over the center of the tibial condyle which is often worn. First, the absence of wear increases the reliability of comparing the medial and lateral resection thicknesses as there is no need to compensate for worn cartilage and bone. Second, the P–D level of the resection is conservative that enables a varus or valgus recut to restore a rectangular extension space with a spacer block like the native knee (Roth, 2015 #60; Roth, 2019 #135). A conservative resection preserves the tibial insertion of the posterior cruciate ligament (PCL) and limits the shortcomings of the use of thick tibial inserts. Second, with the knee in full extension, the V–V plane of the proximal tibia was adjusted, working in 1- to 2-degree increments, until the V–V laxity with a spacer block was negligible in full extension. These verification checks closely restore the native rectangular extension space, laxities, tibial compartment forces, and alignments of the limb and femoral and tibial joint lines.[13,31,33]

From the six available trial anatomic baseplates, the surgeon chose the one that maximized the coverage of the


RESET

RECORD OF VERIFICATION CHECKS FOR CALIPERED KINEMATICALLY ALIGNED TKA

SURGEON | PATIENT CODE | DATE (DD/MM/YYYY)

KNEE ☐ RIGHT ☐ LEFT

OA DEFORMITY ☐ VARUS ☐ VALGUS ☐ PF

A/P OFFSET

EXPOSURE ____ mm TRIALING ____ mm DIFFERENCE 0.0 mm

ACL CONDITION

☐ INTACT ☐ TORN ☐ GRAFT

DISTAL FEMORAL RESECTION

Target Thickness: 8mm Unworn, 6mm Worn (No Cartilage)

When initial thickness misses target - recut or use a washer

MEDIAL CONDYLE		LATERAL CONDYLE	
☐ UNWORN	☐ WORN	☐ UNWORN	☐ WORN
INITIAL THICKNESS	____ mm	INITIAL THICKNESS	____ mm
RECUT [N] [Y]	____ mm	RECUT [N] [Y]	____ mm
WASHER [N] [Y]	____ mm	WASHER [N] [Y]	____ mm
FINAL THICKNESS	0.0 mm	FINAL THICKNESS	0.0 mm

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POSTERIOR FEMORAL RESECTION

Target Thickness: 7mm Unworn, 5mm Worn (No Cartilage)

When initial thickness misses target - recut

MEDIAL CONDYLE		LATERAL CONDYLE	
☐ UNWORN	☐ WORN	☐ UNWORN	☐ WORN
INITIAL THICKNESS	____ mm	INITIAL THICKNESS	____ mm
RECUT [N] [Y]	____ mm	RECUT [N] [Y]	____ mm
FINAL THICKNESS	0.0 mm	FINAL THICKNESS	0.0 mm

TIBIAL RESECTION

Target: Equal Thickness Measured at Base of Tibial Spines

☐ MEDIAL ☐ LATERAL ____ mm

☐ MEDIAL ☐ LATERAL ____ mm

PCL CONDITION

☐ INTACT ☐ TORN ☐ EXCISED

TIBIAL V-V RECUT [N] [Y] ____ deg

TIBIAL SLOPE RECUT [N] [Y] ____ deg

FINAL CHECK WITH SPACER BLOCK AND TRIAL COMPONENTS

NEGLIGIBLE V-V LAXITY IN EXTENSION

2-3 MM OF LATERAL OPENING WITH VARUS LOAD IN 15-30° OF FLEXION

FEMUR SIZE	TIBIA SIZE	INSERT THICKNESS	PATELLA SIZE
		☐ CR ☐ CS	

Fig. 1 Worksheet for intraoperatively recording serial verification checks and caliper measurements of bone resections and positions for a femoral component with 9-mm thick distal femoral condyles and 8-mm thick posterior femoral condyles. The order of the bone cuts progress from distal femoral, posterior femoral, anterior femoral, chamfer femoral, and proximal tibia. Adjusting the thickness of the distal medial and distal lateral femoral resections as measured with a caliper to within 0 ± 0.5 mm of the thickness of the femoral component condyles after compensating for cartilage wear and an approximately 1-mm kerf from the saw cut and 2 mm of cartilage wear when present sets the A–P axis of the femoral component parallel to the F–E plane of the knee. ACL, anterior cruciate ligament; A–P, anterior–posterior; CSA, cross-sectional area; F–E, flexion–extension; PCL, posterior cruciate ligament; TKA, total knee arthroplasty.

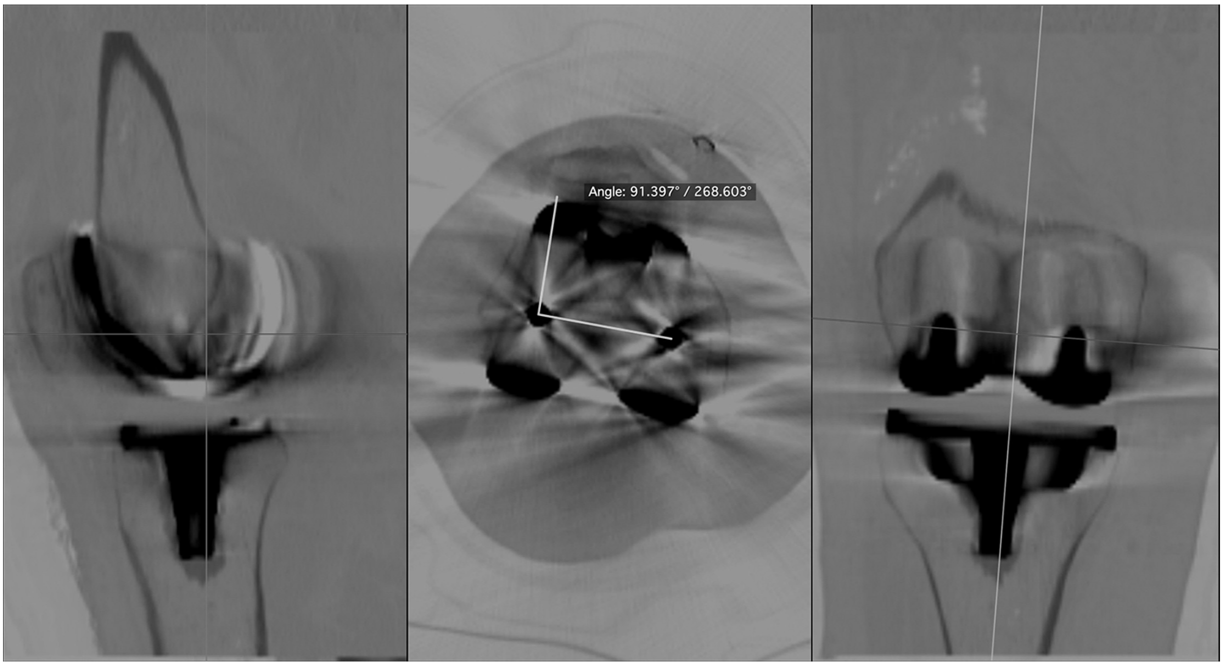

Fig. 2 Computer screenshot shows axial (left) and coronal (right) computer tomographic images of the TKA formatted with use of the multiplane reconstruction (MPR) tool from which measurements were made. A prior study showed that the A–P axis of the femoral component is set parallel to within 0.3-degree external to the F–E plane of the knee by intraoperatively adjusting with a caliper the thicknesses of the femoral resections after compensating for wear and the kerf of the saw blade to within 0 ± 0.5 mm of the distal and posterior condyles of the femoral component.[18] Therefore, orienting the transverse axis parallel to the distal femoral joint line in the coronal image set the vertical axis parallel both the A–P axis of the femoral component and the F–E plane. The axial image shows the orientation of the angle tool with the transverse side parallel to the lugs on the femoral component, which is perpendicular to the F–E plane in the coronal image. A–P, anterior–posterior; F–E, flexion–extension; TKA, total knee arthroplasty.

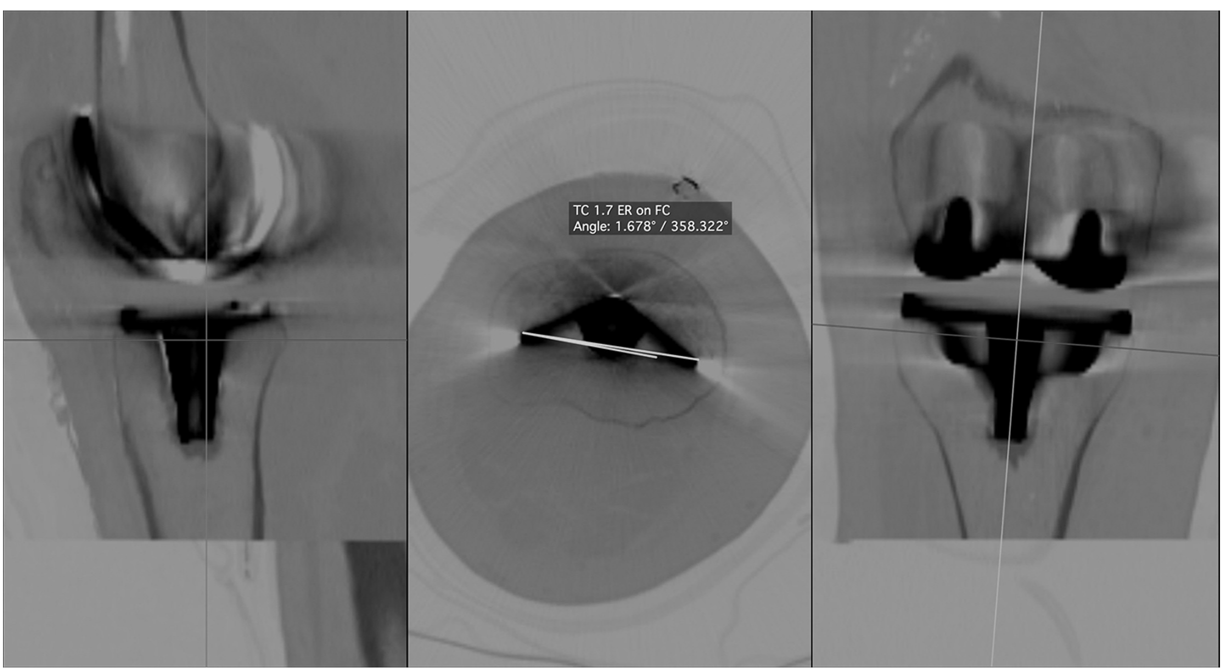

Fig. 3 Computer screenshot shows the plane for measuring the angle between the transverse axes of the anatomic baseplate and calipered KA femoral component, which is just distal to the proximal tibia. The axial image shows the orientation of the propagated angle with the adjusted vertical side now parallel to the fins of the stem, which is perpendicular to both the A–P axis of the anatomic baseplate and the F–E plane. Therefore, the angle represents the deviation of the A–P axis of the anatomic baseplate from the F–E plane of the native knee (+ external, −internal deviation). A–P, anterior–posterior; ER, external rotation; FC, femoral component; F–E, flexion–extension; KA, kinematically aligned; TC, tibial component.

proximal tibia without extending over the cortical edge of the tibial resection. A best-fitting line of the anterior and medial border of the anatomic baseplate parallels or flushes with the cortical edge of the tibial resection and sets the I–E rotation and M–L and A–P positions of the component. The slope was set coincident with the native medial tibial joint line. The slope was adjusted working in 1- to 2-degree increments and the insert thickness was adjusted in 1-mm increments until (1) the caliper measurement of the offset of the anterior tibia from the distal medial condyle of the femoral component with the knee in 90 degrees of flexion matched that of the knee at exposure after adjusting for any cartilage wear on the distal medial femur, and (2) the passive I–E rotation of the tibia on the femoral component approximated ± 14 degrees, which restores the range of native laxity.[33,34] Ligaments were not released. The postoperative correction had no alignment limitations. KA does not reference the femoral and tibial mechanical axes, transepicondylar axis, and tibial tubercle.[30,31]

For the evaluations of rotational alignment and coverage with the anatomic baseplate, two authors (T.Z. and A.J.N.) used the following method to make measurements on an axial CT scan with a 1.25-mm slice thickness obtained the knee in extension with the Perth protocol using image analysis software (Horos, v2.4.1, *horosproject.org*). The multiplane reconstruction (MPR) tool transformed and aligned the images of the knee into axial, sagittal, and coronal images using the "Full Dynamic" and "B/W Inverse" image settings (►**Fig. 2**). The endpoint for fine tuning the orientation of the axial plane was the disappearance and reappearance of the distal surface of the baseplate when scrolling between two adjacent images. A series of steps measured the internal (−) or external (+) rotational deviation of the tibial component on the femoral component, which is a proxy for the deviation of the anatomic tibial baseplate from the F–E plane of the knee (►**Fig. 3**).[18] The pencil tool traced the cortical edge, which computed the cross-sectional area (CSA) of the tibial resection (►**Fig. 4**). The manufacturer provided the CSA of the implanted tibial baseplate at its distal surface.

Statistical Analysis

To quantify reproducibility, three observers (A.J.N., T.Z., and T.S.) independently performed the two radiographic measurements on seven randomly selected imaging studies. The intraclass correlation coefficient (ICC) and the 95% confidence interval (CI) on the ICC were computed for each radiographic measurement with use of a two-factor analysis of variance with random effects. The first factor was the observer with three levels (observers 1, 2, and 3). The second factor was the patients at level 7. An ICC value of >0.9 indicated excellent agreement, 0.75 to 0.90 indicated good agreement, and 0.5 to 0.75 indicated moderate agreement.[35]

Software computed the mean and standard deviation of the deviation of the A–P axis of the anatomic tibial baseplate from the F–E plane of the knee (i.e., A–P axis of the femoral component), and the percent coverage of the proximal tibia ([CSA of baseplate/CSA of proximal tibia × 100] JMP, 10.02, http://www.jmp.com).

Results

The ICC for the internal (−) or external (+) rotational deviation of the tibial component on the femoral component was 0.98 (CI: 0.93–1.0) and for the CSA was 0.99 (CI: 0.97–1.0),

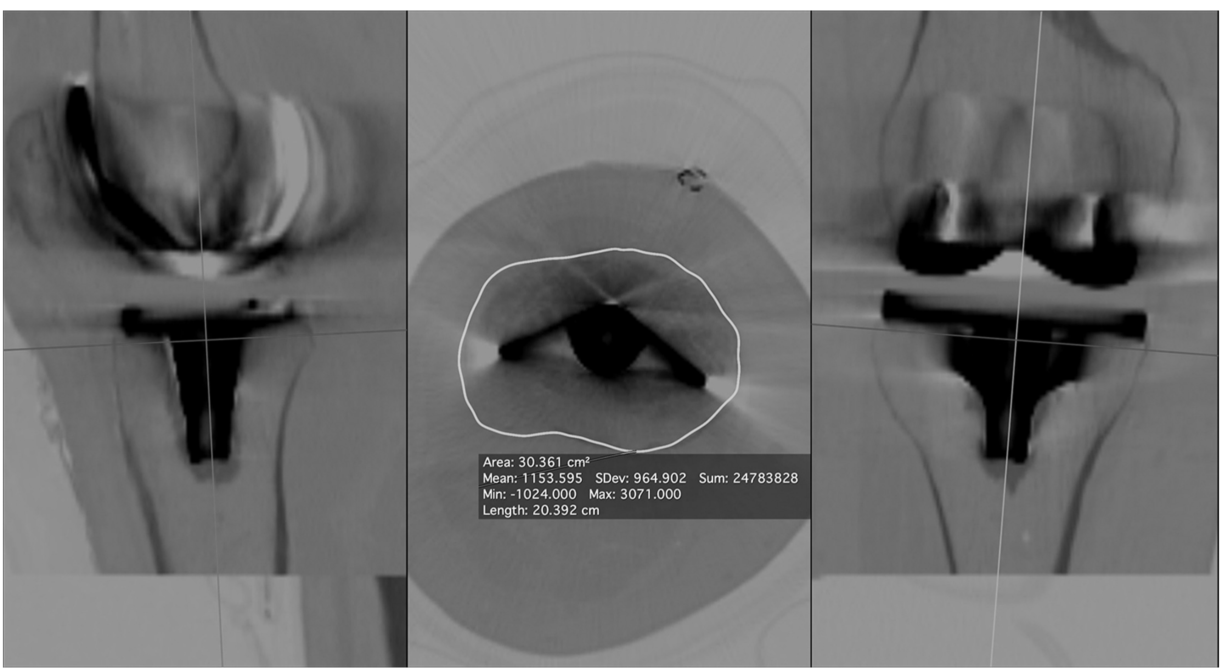

Fig. 4 Computer screenshot shows the plane on the axial image for measuring of the cross-sectional area (CSA) of the proximal tibia, which is parallel to the anatomic baseplate in the sagittal and coronal images. The axial image shows the computation of the CSA (30.361 cm^2) from tracing the cortical rim of the tibia with the pencil tool. The percent coverage of the proximal tibia = (CSA of baseplate [provided by the manufacturer]/CSA of proximal tibia) × 100. Max, maximum; Min, minimum; SDev, standard deviation.

Table 1 Preoperative patient demographics and clinical and radiographic characteristics

Preoperative demographics and clinical and radiographic characteristics	Number of patients or knees	Mean (SD) or *n* (%)	Range
Demographics			
Age (y)	$n = 146$	68 (8.1)	40–85
Sex (male)	$n = 146$	65	
Body mass index (kg/m^2)	$n = 146$	30.7 (5.8)	18–45
Preoperative motion, deformity, ACL condition, and Kellgren–Lawrence score			
Extension (degrees)	$n = 146$	8 (5.7)	0–25
Flexion (degrees)	$n = 146$	112 (8.1)	80–130
Varus (+)/valgus (−) deformity (degrees)	$n = 146$	5 (11.0)	−22–20
ACL condition	$n = 146$	Intact (66%), torn (30%), reconstructed (4%)	
Kellgren–Lawrence score	$n = 146$	1 (0), 2 (3), 3 (47), 4 (50)	
Preoperative function			
Oxford Score (48 is best, 0 is worst)	$n = 146$	23 (8.5)	4–41
Knee Society Score	$n = 146$	36 (14.1)	10–48
Knee Function Score	$n = 146$	53 (17.7)	0–70

Abbreviations: ACL, anterior cruciate ligament; SD, standard deviation.

which indicates excellent agreement between the radiographic measurements made by three observers.

For the 146 patients available for study, the mean age at time of surgery was 68 ± 8.1 years (range: 40–85), and 55% (81 of 146) were female. ►**Table 1** summarizes preoperative patient demographics, motion, range of knee deformities, function, Kellgren–Lawrence arthritis classification, and condition of the anterior cruciate ligament (ACL).

The mean deviation of the A–P axis of the anatomic baseplate from the A–P axis of the femoral component was 2-degree external $\pm$ 5 degrees (range: −10-degree internal to 14-degree external), which is the proxy for the deviation of the tibial component from the F–E plane of the native knee (►**Fig. 5**). The mean coverage of the proximal tibia was $87 \pm 6\%$ (CSA of baseplate/CSA of proximal tibia $\times$ 100; ►**Fig. 6**). Three patients had >2 mm of an overhang of the tibial component on the proximal tibia. For these patients, the mean deviation of the anatomic baseplate from the femoral component was 10-degree external $\pm$ 6 degrees, and the mean CSA of coverage was $92 \pm 4\%$, which were comparable to those of all patients in the study.

Discussion

The present study reports the use of an anatomically designed tibial baseplate with calipered KA TKA. The two most important findings were that a best-fit plane of the anatomic baseplate that sets the mean A–P axis within 2-degree external $\pm$ 5 degrees from the F–E plane of the knee and covers a mean of $87 \pm 6\%$ of the proximal tibia.

Several limitations might affect the generalization of the findings. First, the results of the present study apply to one implant design and might not be generalizable to others. Second, these results are from a single surgeon's case series and require confirmation by others. However, a previously published in vitro study of KA showed that the level of surgical experience does not affect the reproducibility of the best-fit plane and the alignment to the F–E plane of the knee, which suggests that these findings might be generalizable.[19]

The present study reported a mean deviation of 2-degree external $\pm$ 5 degrees and variability (range: −10-degree internal to 14-degree external) from the F–E plane, which is comparable or better than other studies of KA and MA TKA and also compatible with high function. One study of calipered KA TKA, reported a mean deviation of −1-degree internal $\pm$ 5 degrees and variability (range: −11-degree internal to 12-degree external) from the F–E plane after setting the A–P axis of symmetric tibial component parallel to the long axis of the boundary of the lateral tibial condyle. This variability resulted in a 44-point median (interquartile range; 40–45) Oxford Knee Score, which indicated high function.[18] The reproducibility of the use of a best-fit plane of the anatomic baseplate to the KA targets the F–E plane of the native knee is greater than the reproducibility reported for MA targets that use bony tibial landmarks. Eleven arthroplasty surgeons using MA targets, each working with 10 cadaveric specimens, reported high deviations of −43-degree internal to 42-degree external from the line connecting the medial border of the tibial tubercle to the center of the posterior cruciate ligament fossa, −40-degree internal to 46-degree external from the line connecting the medial one-third of the tibial tubercle to the center of the posterior cruciate ligament fossa, and −20-degree internal to 32-degree external from the line connecting the most anterior point of the tibial tubercle to the center of the posterior cruciate ligament fossa.[24] The low reproducibility of the use of these MA targets to set I–E rotation

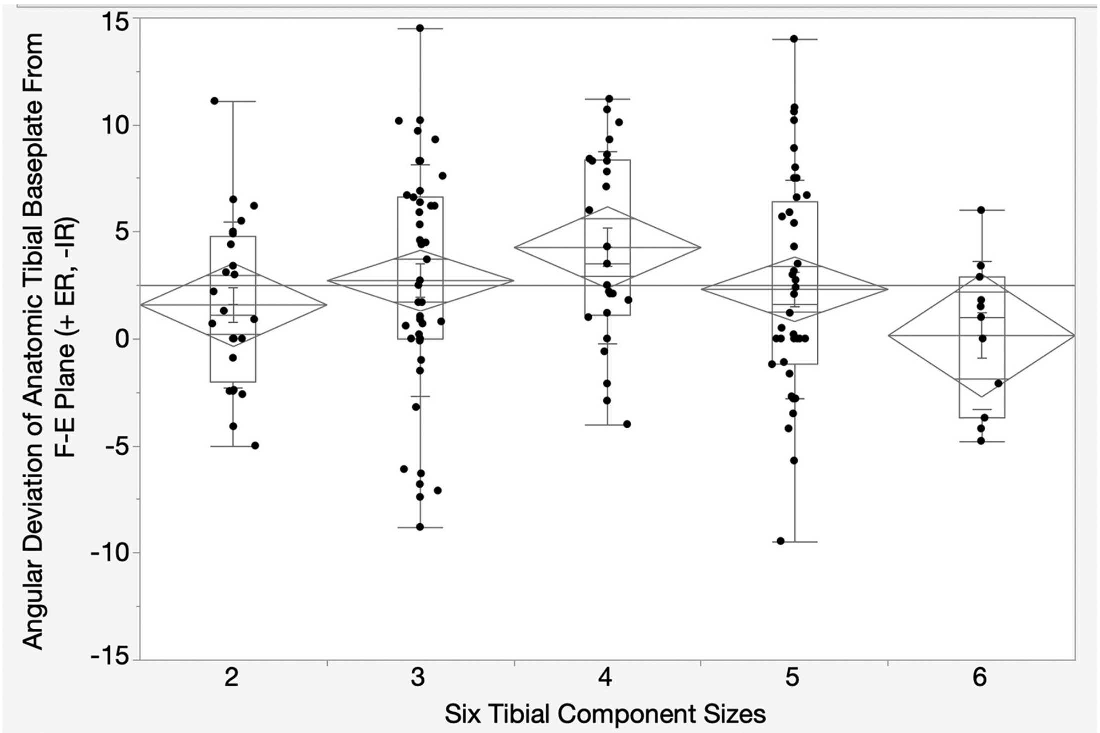

Fig. 5 The quantile box plots for the five tibial component sizes that were used show the deviation of the A–P axis of the anatomic baseplate from the femoral component which is a proxy for the deviation from the F–E plane of the native knee. The gray transverse line represents the grand mean of 2-degree external ± 5 degrees. The upper and lower bound of the red boxes represents the 75 and 25 quantiles and the red transverse line within the box represents the median. The upper and lower bounds of the green diamond represent the 95% confidence interval of the mean and the green transverse line bisecting the diamond represents the mean. A–P, anterior–posterior; ER, external rotation; F–E, flexion–extension; IR, internal rotation.

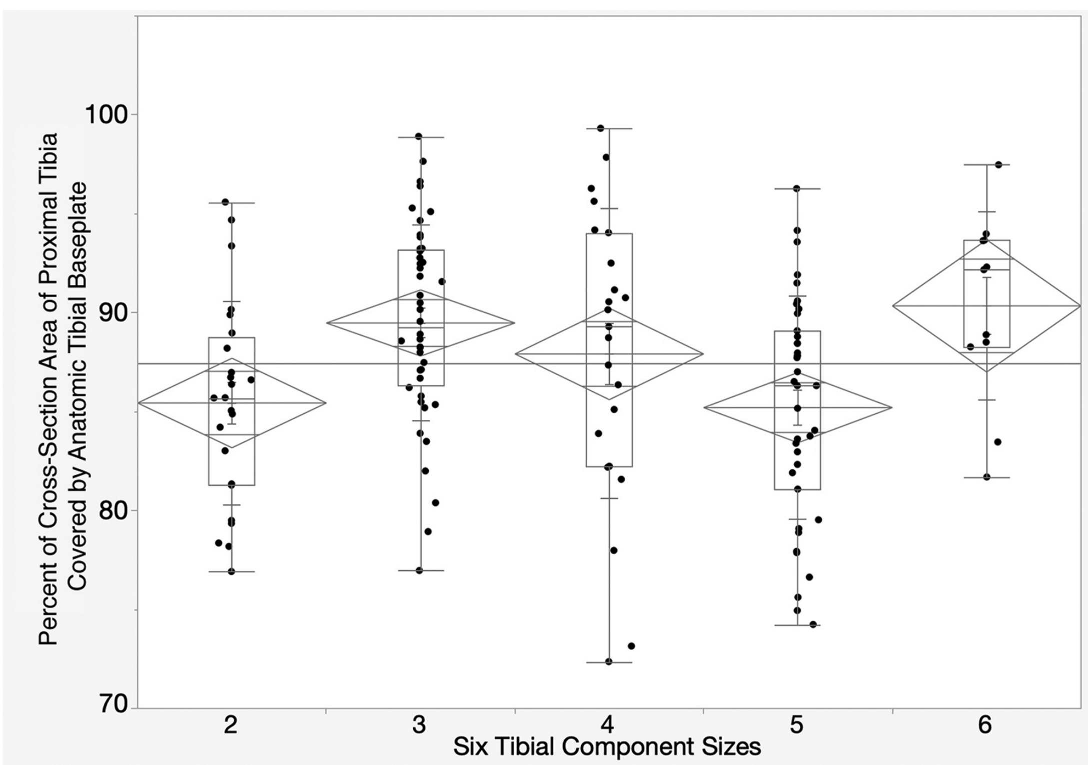

Fig. 6 The quantile box plot of each tibial component size shows the distribution of the percent coverage of the proximal tibia by the anatomic tibial baseplate. The gray transverse line represents the grand mean of 87 ± 6%.

of the tibial component is caused by the 15 mm of mediolateral deviation of the location of the tibial tubercle from the medial border of the tibia in the native knee.[17] The anatomic baseplate used in the present study with calipered KA eliminates the use of all tibial tubercle targets, which enabled the best-fit method to orient the A–P axis of the baseplate to the F–E plane knee with higher reproducibility.

The in vivo mean coverage of $87 \pm 6\%$ of the proximal tibia achieved with a best-fit method of the anatomic baseplate and calipered KA in the present study was comparable or higher than in vitro mean coverage reported for other asymmetric and symmetric designs for use with MA targets. One in vitro study set an asymmetric and three symmetric tibial baseplates to the MA target of the medial one-third of the tibial tubercle, which resulted in mean coverage ranging from 80 to 84% that is smaller than the present study.[36] Another in vitro study showed that an asymmetric baseplate set to the MA target of the medial one-third of the tibial tubercle resulted in higher tibial coverage (92% compared with 85–87%), and more cortical support (posteromedial region of the tibia) than a symmetric baseplate.[20] These studies suggest that the use of the anatomic and asymmetric baseplate can provide high coverage and posteromedial tibial support.

Conclusion

In conclusion, the anatomic baseplate evaluated in the present study can be used with calipered KA TKA as the best-fit method closely set I–E rotation of the A–P axis of the baseplate parallel to the F–E plane of the knee and covered a high percentage of the proximal tibia.

Conflict of Interest
None declared.

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