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Does Calipered Kinematically Aligned TKA Restore Native Left to Right Symmetry of the Lower Limb and Improve Function?

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ABSTRACT

Background: Kinematically aligned total knee arthroplasty (KA TKA) strives to restore the native left to right symmetry of the lower limb; however, the reproducibility of achieving this target is unknown. The present study determined the proportion of patients with left to right symmetry and the improvement in patient-reported function after calipered KA TKA.
Methods: A review of 562 postoperative scanograms identified 102 patients (53 women) with a KA TKA in one limb, no other skeletal abnormalities in either limb, and symmetrical rotation between limbs on the scanogram. All patients were treated with primary TKA that used caliper measurement of the thicknesses of the femoral bone and tibial bone resections to kinematically align the components. The hip-knee-ankle (HKA) angle, distal lateral femoral angle (DLFA), and proximal medial tibial angle (PMTA) were measured. Patient-reported Oxford Knee Score (OKS) measured preoperative and postoperative functions.
Results: The proportion of patients with a difference in the HKA angle, DLFA, and PMTA between limbs within $\pm 3^\circ$, $>3^\circ$ varus, and $<-3^\circ$ valgus was 95%, 2%, and 3%, respectively, for the HKA angle; 97%, 1%, and 2%, respectively, for the DLFA; and 97%, 2%, and 1%, respectively, for the PMTA. The mean OKS improved from 20 preoperatively to 44 points (range 18-48 points) at 15 months postoperatively.
Conclusion: Calipered KA TKA restored native left to right symmetry of the HKA angle, DLFA, and PMTA in nearly all patients with negligible risk of varus alignment of the tibial component with respect to the native tibial joint line. The mean postoperative OKS indicated clinically important improvement in patient-reported function.

One long-held tenet of total knee arthroplasty (TKA) is that implant durability is promoted by an overall postoperative limb within $0^\circ \pm 3^\circ$ of the mechanical axes, which is the angle of the intersection of a line connecting the centers of the femoral head and knee and a line connecting the centers of the knee and talus [1]. Substantial resources have been dedicated to the use of computer-assisted navigation, robotics, and patient-specific instrumentation under the hypothesis that achieving a more reproducible neutral mechanical axis will promote durability or improve function [2]. Five long-term follow-up studies have not shown any differences in implant survival rate between the TKA cases with neutral and outlier alignments [3–7]. Although aligning a higher portion of limbs within $0^\circ \pm 3^\circ$ of the mechanical axes is possible, it might not improve function and implant survival [1,6,7].

Kinematic alignment (KA) strives to restore the native left to right symmetry and prearthritic alignment of the limb, distal and posterior femoral joint lines, and proximal tibial joint line [8–14] (Figs. 1-3). KA is of interest because 3 meta-analyses, 3 randomized trials, and a national multicenter study showed that patients with KA TKA reported significantly better pain relief, function, flexion, and a more normal feeling knee than patients treated with mechanical alignment (MA) [8,9,15–20], whereas 2

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The study was approved by our ethical committee.

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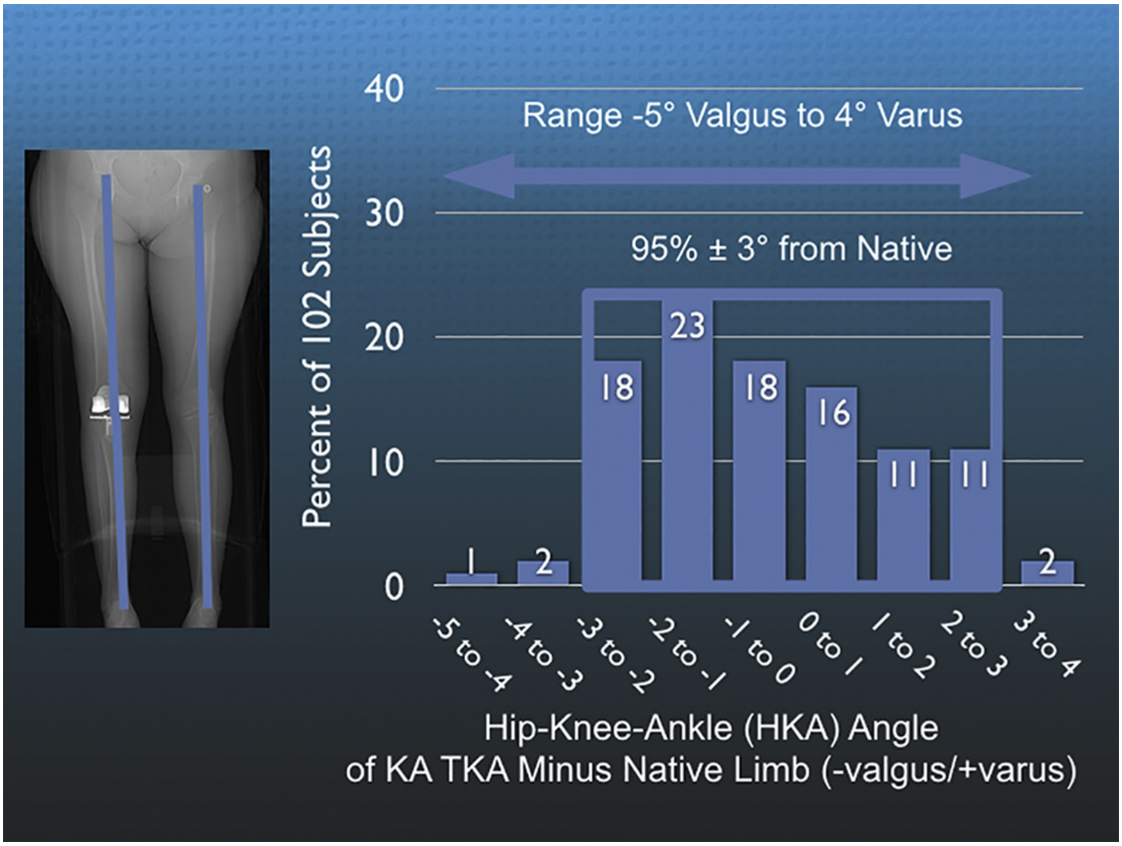

Fig. 1. Illustration shows a scanogram of a patient with the measurement of the mechanical alignment of the limb as the HKA angle in the KA TKA and contralateral native knee (left) and a column graph showing that 95% of patients treated with a KA TKA had a difference in the HKA angle within ±3° between limbs (right). HKA, hip-knee-ankle; KA TKA, kinematically aligned total knee arthroplasty.

randomized trials showed similar clinical outcomes between KA and MA [13,21].

KA compensates for cartilage and bone wear in the medial tibia and consistently restored the native tibial joint line in the osteoarthritic knee with a varus deformity according to a 3-dimensional analysis [22]. However, KA sets 55% of tibial components in >3° of varus with respect to a line perpendicular to the tibial mechanical axis, which is a varus outlier according to Parratte et al; and sets 100% of tibial components in >0° of varus with respect to a line perpendicular to the tibial anatomic axis of the knee, which is a varus outlier according to Ritter et al [6,23,24]. Varus alignment of the tibial component concerns practitioners of MA because there is a risk of varus subsidence of the tibial component [23,25]. Although follow-up at 10 or more years after KA TKA has not been reported, several authors have reported a negligible incidence of varus failure of the tibial component at 2- to 9-year follow-up [9–11,13,26]. Reasons offered for the low early and midterm implant failure rate are that KA sets the joint line of the knee parallel in orientation relation to the floor during single-leg and double-leg stance [17,27,28], intraoperative forces in the medial and lateral tibial compartments after KA TKA without ligament release are close to the native knee and 3-6 times lower than after MA TKA with ligament release [24].

Left to right angular features are considered symmetric when skeletally mature patients with no radiographic evidence of skeletal deformity have a difference in the distal lateral femoral angle (DLFA) and the proximal medial tibial angle (PMTA) between limbs within ±3°, which occurred in 96% of patients [29]. Second-generation patient-specific instrumentation designed for performing KA has inaccuracies as 22% of limbs were aligned outside ±3° of the preoperative plan [21]. Caliper measurements of the thicknesses of the distal and posterior femoral resections and tibial bone resections are quality assurance steps used to KA the components coincident to the native joint line [12,14,30]. Whether calipered KA restores the left to right angular symmetry between limbs in the coronal plane is unknown.

The present study analyzed patients treated with calipered KA TKA in one limb with no other skeletal abnormalities in either limb, and determined the proportion of patients with a difference in the hip-knee-ankle (HKA) angle, DLFA, and PMTA between limbs within ±3°, and the improvement in patient-reported function.

Materials and Methods

With approval of our institutional review board (IRB 918840-1), we retrospectively identified all patients treated with a TKA between August 2014 and March 2016 by the senior author (SMH) that are prospectively followed in a registry. All patients fulfilled the Centers for Medicare & Medicaid Services guidelines for medical necessity for TKA treatment. Included were osteoarthritic knee with (1) radiographic evidence of Kellgren-Lawrence grades II-IV arthritic change or osteonecrosis; (2) any severity of clinical varus or valgus deformity as measured non–weight bearing with a goniometer (range from −30° valgus to 20° varus); and (3) any severity of flexion contracture [31]. During this period, all patients who consented for a primary TKA were treated with KA and quality

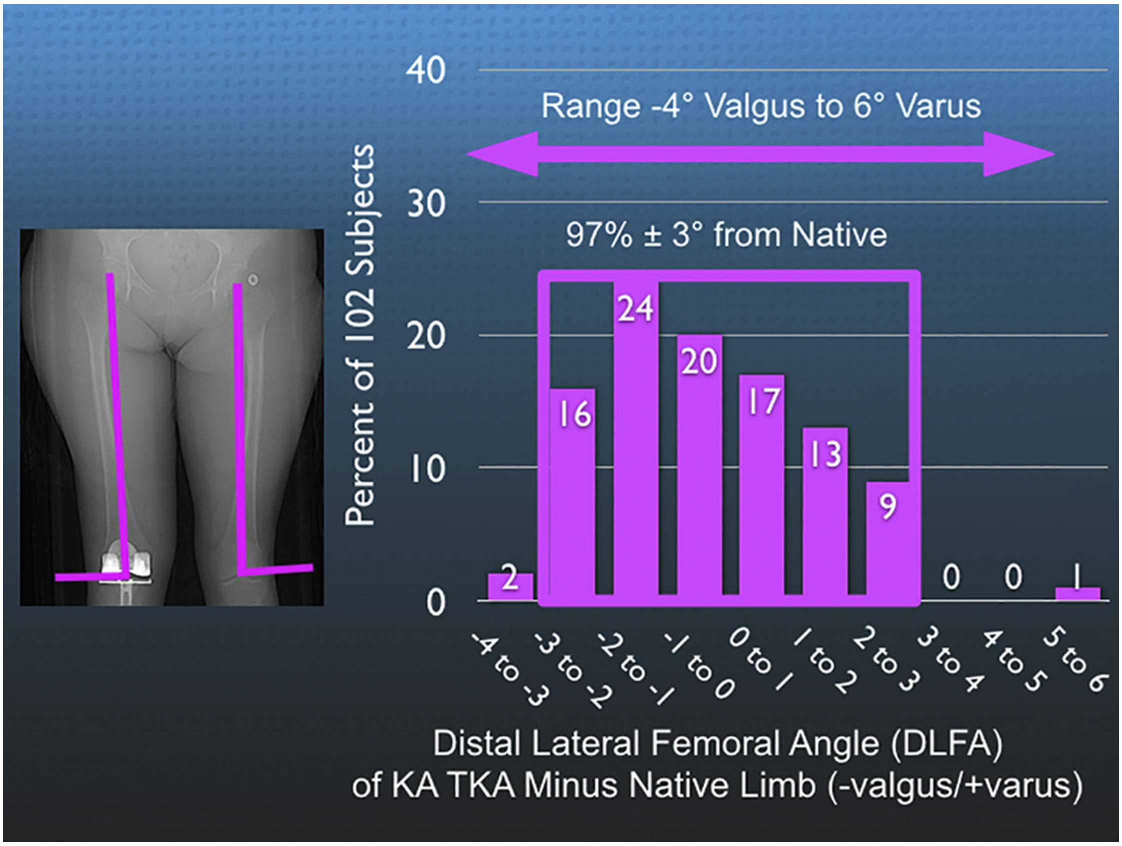

Fig. 2. Illustration shows a scanogram of a patient with the measurement of the DLFA in the KA TKA and contralateral native knee (left) and a column graph showing 97% of patients treated with a KA TKA had a difference in the DLFA within ±3° between limbs (right). DLFA, distal lateral femoral angle.

assurance steps of measuring and adjusting the thicknesses of the distal femoral, posterior femoral, and proximal tibial resections with a caliper. Cemented cruciate-retaining implants with patella resurfacing were implanted (Persona CR, Zimmer Biomet, Warsaw, IN) [12,14].

The following sequence of surgical steps, caliper measurements, and adjustments were used to quality assure kinematically aligning the femoral and tibial components coincident to the native joint lines [12,14]. Identify the distal femoral condyles with cartilage wear. Remove partial cartilage wear to bone. Apply a distal femoral referencing guide that compensates 2 mm when cartilage is worn on the distal medial femoral condyle in the varus knee, and 2 mm when cartilage is worn on the distal lateral femoral condyle in the valgus knee (Fig. 4). Measure the thicknesses of the distal femoral resections with a caliper. Adjust the thickness of each resection to match the thickness of the condyles of the femoral component after compensating for cartilage wear and kerf to within ±0.5 mm. When the distal resection is 1-2 mm too thin, angle the blade in the saw slot and recut the bone using the ~1 mm thickness of the sawblade as a gauge. When the distal resection is 1-2 mm too thick, apply a 1 or 2 mm thick washer on the peg of the 4-in-1 chamfer block, which shims a corrective gap between the condyle of the femoral component and distal femur. Position the 4-in-1 chamfer block by drilling holes through a posterior femoral referencing guide set at 0° rotation. Measure the thicknesses of the posterior femoral resections with a caliper before making the anterior and chamfer cuts. Adjust the thickness of each resection to match the thickness of the condyles of the femoral component after compensating for cartilage wear and kerf to within ±0.5 mm. When a posterior femoral resection is 1-2 mm too thick or too thin, eccentrically elongate the pin hole in the direction of the correction and translate the 4-in-1 chamfer block as needed. Secure the chamfer block in the corrected position with compression screws. Make the anterior resections and chamfer femoral resections. These caliper measurements and adjustments are quality assurance steps that align the femoral component coincident to the native distal and posterior femoral joint lines. Remove medial and lateral osteophytes. Apply a conventional extramedullary tibial resection guide to the ankle and place an angel wing in the saw slot of the guide. Adjust the varus-valgus angle of the tibial resection guide until the saw slot parallels the proximal tibial articular surface after compensating for wear. Adjust the flexion-extension angle of the tibial resection guide until and the angel wing parallels the slope of the medial tibia after compensating for wear. Resect the proximal tibia retaining the posterior cruciate ligament. Measure the thickness of the medial and lateral tibial condyles at the base of the tibial spines. When one tibial condyle is thinner than the other by 1 mm or more expect tightness in that compartment and slackness in the other when assessing varus-valgus laxity with trial components with the knee in full extension. When asymmetric laxity is observed, use a 2° varus or valgus recut guide to fine-tune the tibial resection until the laxity is 1° or less in full extension like the native knee [32]. These caliper measurements and adjustments are quality assurance steps that the tibial component is coincident to the native proximal tibial joint line and coaligns the components to the 3 rotational axes of the native knee [12,14].

On the day of discharge, each patient had an anteroposterior, rotationally controlled, non–weight bearing, long-leg computed tomography scanogram of both limbs [10,11,14]. Because simultaneous flexion of the knee and hip rotation causes large changes of

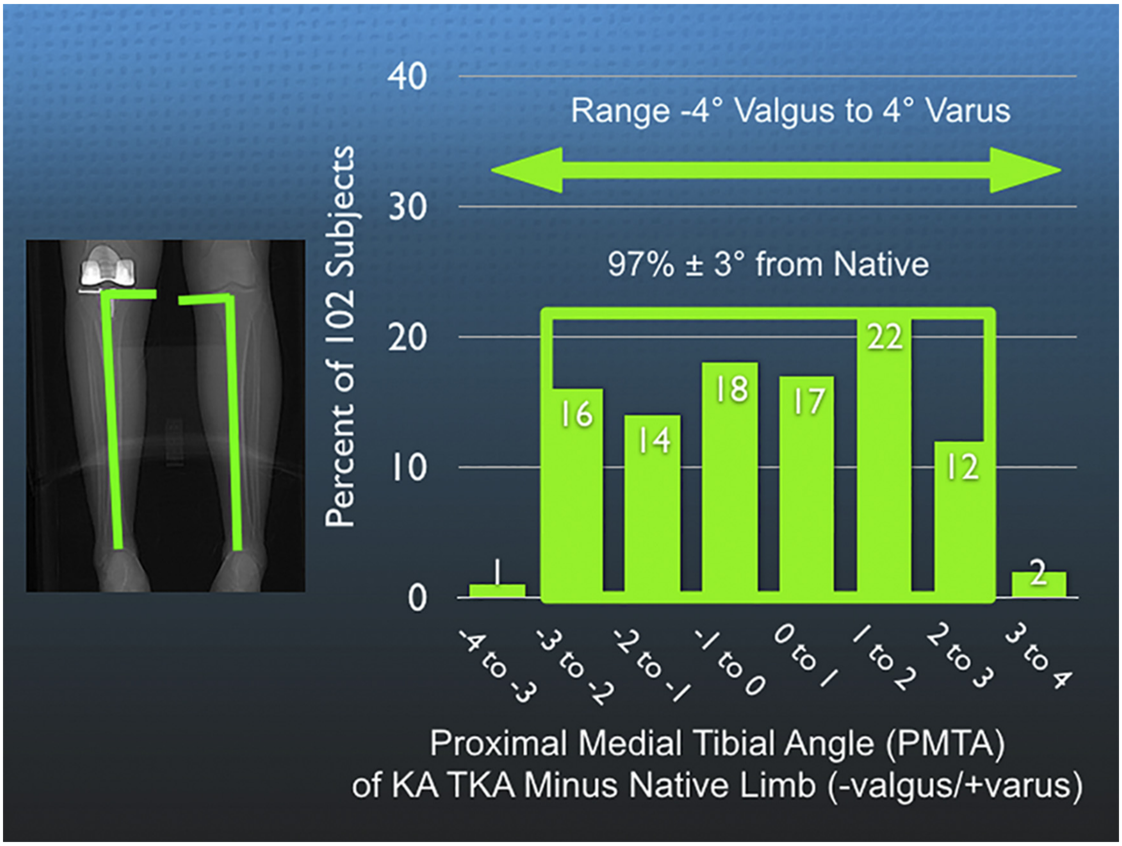

Fig. 3. Illustration shows a scanogram of a patient with the measurement of the PMTA in the KA TKA and contralateral native knee (left) and a column graph showing a 97% of patients treated with a KA TKA had a difference in the PMTA within ±3° between limbs (right). PMTA, proximal medial tibial angle.

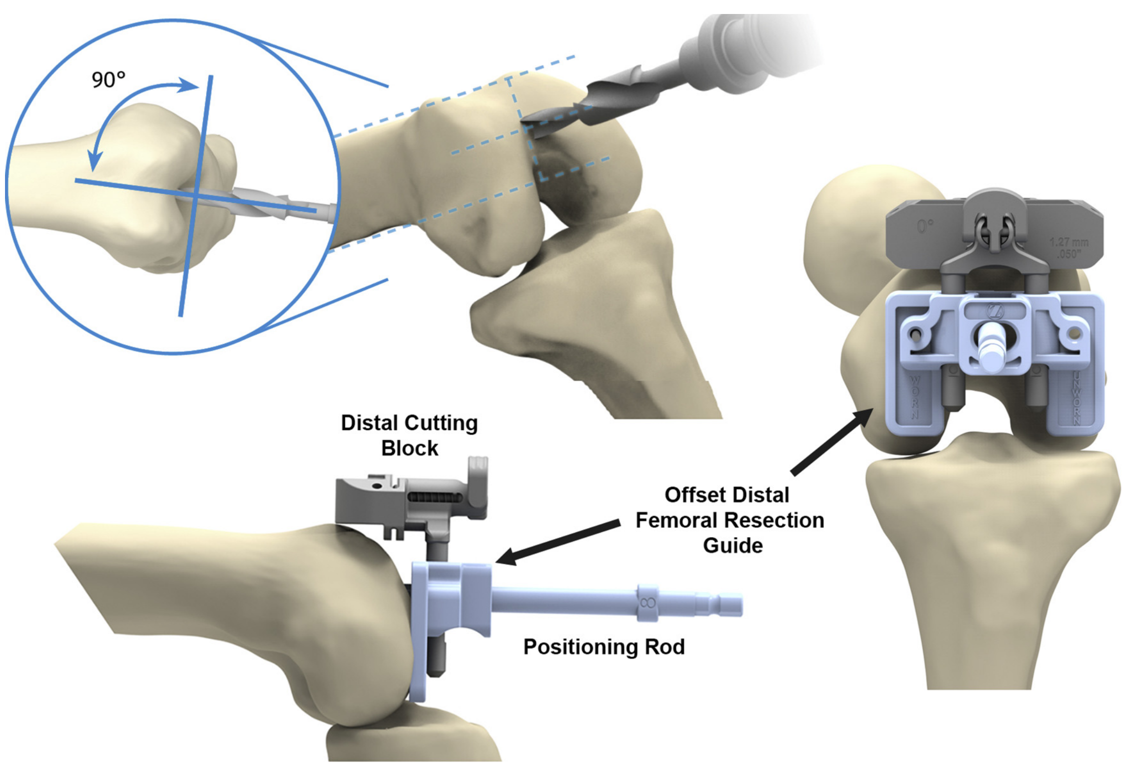

Fig. 4. Schematic shows the use of an offset distal femoral reference guide inserted into the cutting block and passed over a positioning rod. The positioning rod is inserted 8-10 cm through a hole drilled into the metaphysis of the distal femur and set parallel to the anterior femoral shaft and perpendicular to the distal femoral articular surface to minimize flexion of the femoral component. The offset has a 2-mm buildup to compensate for the worn cartilage on the distal femoral condyles with arthritic changes.

the HKA angle, DLFA, and PMTA, the imaging technician was taught to quality control the rotation of the limbs between patients by positioning the knee in maximum extension and repeating the scanogram until the flange of the femoral component was inside the most medial and lateral edges of the posterior condyles [33,34]. When the area and shape of the interosseous space and the overlap or gap between the tibia and fibula were the same within a patient, the rotation between limbs was considered symmetric (Fig. 5) [34]. From the 562 knees available for study, 2 authors (AJN and AKS) blinded to the function scores identified a subset of 102 patients (53 women) with a KA TKA in one limb, no other skeletal abnormalities in either limb, and symmetrical hip rotation between limbs within a patient. Hence, 460 patients were excluded because the scanogram showed degenerative arthritis (N = 117) or a TKA (N = 188) in the contralateral knee, a healed fracture or degenerative arthritis or arthroplasty of the hip or ankle in either limb (N = 42), or asymmetric rotation between limbs within a patient (N = 113).

Two authors (AJN and AKS) identified the following landmarks described by Bellemans and measured the alignments using free image analysis software (OsiriX Imaging Software, http://www.osirix-viewer.com) [1]. The center of the femoral head was determined by best-fitting a circle. The center of the knee was determined as the midline between the femoral condyles at the level of the distal joint line of the femoral component or native femur. The center of the ankle was determined as the midwidth of the talus. The mechanical femoral axis was the line from the center of the femoral head to the center of the knee. The mechanical tibial axis was the line from the center of the knee to the center of the ankle. The MA of the limb was the HKA angle between a line connecting the mechanical axes of the femur and tibia (a positive angle was varus and a negative angle was valgus; Fig. 1). The DLFA was the lateral angle between the distal femoral joint line and the mechanical axis of the femur (varus >90° and valgus <90°; Fig. 2). The PMTA was the medial angle between the proximal tibial joint line and the mechanical axis of the tibia (varus <90° and valgus >90°; Fig. 3).

The preoperative non–weight bearing varus or valgus deformity and flexion contracture as measured with a goniometer and patient-reported Oxford Knee Score (OKS; 48 is best and 0 is worst) were recorded for the included and excluded patients. For the included patients, postoperative patient-reported OKS was obtained at final follow-up.

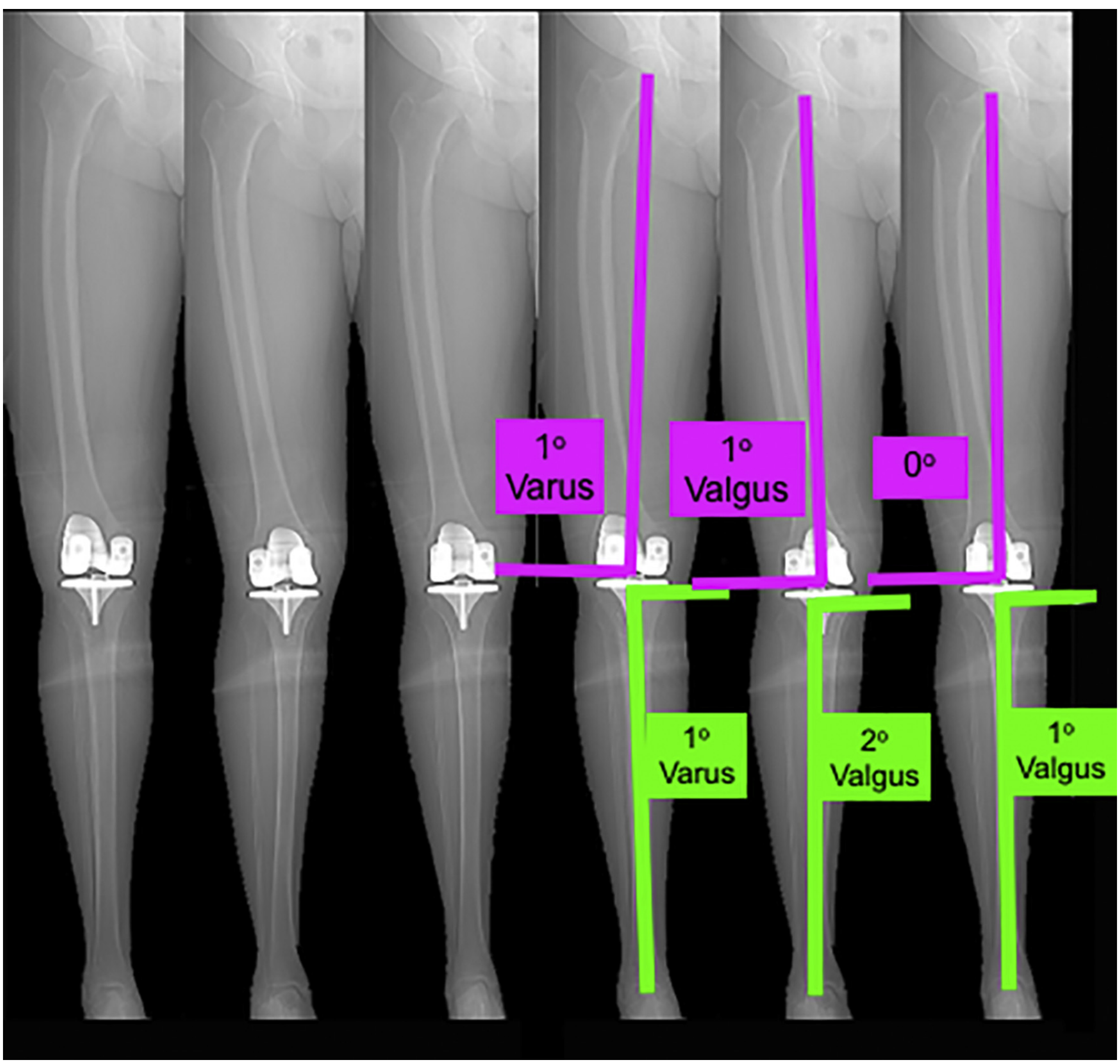

Fig. 5. Composite shows 3 anteroposterior scanogram projections of the same limb with different shapes of the interosseous space between the tibia and fibula (left 3 radiographs). Small differences in the shape of the interosseous space between limbs cause several degrees of varus and valgus variability in the measurement of the distal lateral femoral angle (pink lines and text) and proximal medial tibial angle (green lines and text) not related to the alignment of the components. Patients were only included when both limbs had similar shapes of the interosseous space indicating symmetrical rotation between limbs (Figs. 1-3).

Statistical Analysis

To quantify reproducibility, 3 observers (AJN, AKS, and SMH) independently performed the 3 radiographic measurements on both limbs on 20 randomly selected imaging studies. The intraclass correlation coefficient (ICC) and the 95% confidence interval (CI) were computed for each measurement with use of a 2-factor analysis of variance with random effects. The first factor was the observer with 3 levels (observers 1, 2, and 3). The second factor was the measurement of each of the 20 patients. An ICC value of >0.9 indicated excellent agreement, 0.75-0.90 indicated good agreement, and 0.5-0.75 indicated moderate agreement [35].

Continuous variables (ie angles) were reported as mean ± standard deviation or median (range), and discrete variables (patient-reported outcomes) were reported as number (%). We assessed the significance of the difference of the HKA angle, DLFA, and PMTA between the KA TKA and the native limb with a paired Student *t* test. A paired Student *t* test determined whether the preoperative OKS improved at final follow-up at an average of 15 months (JMP, version 12.1; http://www.jmp.com). Significance was $P < .05$.

Results

The ICC for the KA TKA and the native limb was 0.93 (CI 0.82-0.97) and 0.95 (CI 0.87-0.98), respectively, for the HKA angle, 0.96 (CI 0.90-0.98) and 0.93 (CI 0.81-0.97), respectively, for the DLFA, and 0.89 (CI 0.77-0.95) and 0.88 (CI 0.75-0.95), respectively, for the PMTA, which indicates good to excellent agreement between the radiographic measurements made by 3 observers.

The average age of the 102 patients was 68 ± 8 years, 53 were women, and the body mass index averaged 29 ± 5 kg/m^2 (Table 1). The preoperative Kellgren-Lawrence classification of osteoarthritis was II in 6%, III in 54%, and IV in 40% as determined by standing full extension and 45° flexion knee radiographs. At 15 months, the OKS was not different between patients with a Kellgren-Lawrence classification of II (44 ± 2.5 points), III (44 ± 5.7 points), and IV (44 ± 6.0 points) ($P = .9107$). The clinical varus or valgus deformity as measured non–weight bearing with a goniometer ranged from −30° valgus to 20° varus. No medial or lateral collateral ligament, lateral retinacular, or posterior cruciate ligament releases were performed. One patient had an additional surgery, which consisted of an open lateral release and medial reefing for patella subluxation that developed without trauma 7 months after the index procedure because of a surgeon error that set the femoral component in excessive flexion (16°) [36].

Descriptive statistics of the HKA angle, DLFA, and PMTA measurements of the calipered KA TKA indicated close agreement with the contralateral native limb (Table 2; Figs. 1-3). The proportion of KA TKAs within ±3°, >3° varus, and >3° valgus of the contralateral native limb was 95%, 2%, and 3%, respectively, for the HKA angle; 97%, 1%, and 2%, respectively, for the DLFA; and 97%, 2%, and 1%, respectively, for the PMTA. The mean (range) for the KA TKA and native limb was 0° ± 3° (7° to −7°) and 1° ± 3° (8° to −7°), respectively, for the HKA angle, 87° ± 3° (93°-81°) and 87° ± 2° (92°-82°), respectively, for the DLFA, and 87° ± 2° (91°-83°) and 87° ± 2° (91°-80°), respectively, for the PMTA. Of the 3 angles measured, the largest average difference between limbs occurred for the HKA angle, but this difference was <1° (Table 2).

The mean OKS could be obtained from 98 patients. One patient deceased before the final follow-up, one patient suffered a stroke, and one patient was lost for follow-up. The OKS improved from 20 points (range 3-38 points) preoperatively to 44 points (range 18-48 points) at a mean follow-up of 15 ± 5 months (range 6-25 months) ($P < .0001$) (Fig. 6). The proportion of patients with postoperative OKS categorized by Kalairajah groupings was 79% excellent (>41), 10% good (34-41), 7% average (27-33), and 4% poor (<27) [37].

Discussion

Measuring the difference in alignment of the limb and joint lines from desired targets is an important quality control metric for judging success of the surgical technique and optimizing outcomes after TKA [3–7]. The most important findings of the present study were that calipered KA restored native left to right symmetry of the HKA angle, DLFA, and PMTA within 0° ± 3° in nearly all patients. The postoperative OKS indicated clinically important improvement in patient-reported function.

Four limitations should be discussed. First, the proportion of patients with restoration of the native left to right symmetry was determined from a subset of 102 of 562 patients (18%) because reliable measurements could not be made in the other patients because of degenerative arthritis (N = 117) or a TKA (N = 188) in the limb without the KA TKA, a healed fracture or degenerative arthritis or arthroplasty of the hip or ankle (N = 42), or asymmetric rotation between limbs (N = 113). A post-hoc analysis comparing 8 parameters between this subset of patients and all patients in 2 representative studies of KA TKA showed no clinically important differences in the level of preoperative extension, flexion, and varus-valgus deformities and preoperative OKS, which makes a

Table 1
Preoperative Patient Demographics, Clinical Characteristics, and Preoperative and Postoperative Oxford Knee Scores.

Preoperative Demographics, Clinical Characteristics Oxford Knee Scores	Number of Patients or Knees, N	Mean (SD) or Numbers (%)	Range
Demographics			
Age, y	102	68 (8.0)	50-86
Sex (male)	102	49	
Body mass index, kg/m^2	102	29 (5.0)	17-43
ASA score (1 is best and 4 is worst)	102	1 (0%), 2 (73%), 3 (20%), 4 (8%)	
Preoperative motion and deformity			
Extension, °	102	14 (8.0)	0-50
Flexion, °	102	113 (7.8)	90-130
Varus (+)/valgus (−) deformity, °	102	−2 (12.9)	−30 to 20
Function			
Preoperative Oxford Score (48 is best and 0 is worst)	102	20 (8.0)	3-38
Postoperative Oxford Score	101 (1 deceased)	44 (6.4)	18-48

ASA, American Society of Anesthesiologists; SD, standard deviation.

Table 2
Descriptive Statistics of Alignment Measurements of KA TKA and Normal Native Contralateral Knee.

Alignment Measurements of KA TKA and Native Contralateral Limb	Average (SD), °	95% Confidence Interval, °	Range, °
KA TKA hip-knee-ankle angle[a]	0.4 ± 2.9	−0.2 to 0.9	−6.8 to 6.8
Native limb hip-knee-ankle angle[a]	0.8 ± 3.0	0.2-1.4	−7.4 to 8.0
KA TKA distal lateral femoral angle[b]	87.1 ± 2.5	86.6-87.5	81-93
Native distal lateral femoral angle[b]	87.4 ± 2.2	87-87.8	82-92
KA TKA proximal medial tibial angle[c]	87.2 ± 1.7	86.8-87.5	83-91
Native proximal medial tibial angle[c]	87.1 ± 2.2	86.7-87.5	80-91

KA TKA, kinematically aligned total knee arthroplasty; SD, standard deviation.
[a] Varus positive and valgus negative.
[b] Varus >90° and valgus <90°.
[c] Varus <90° and valgus >90°.

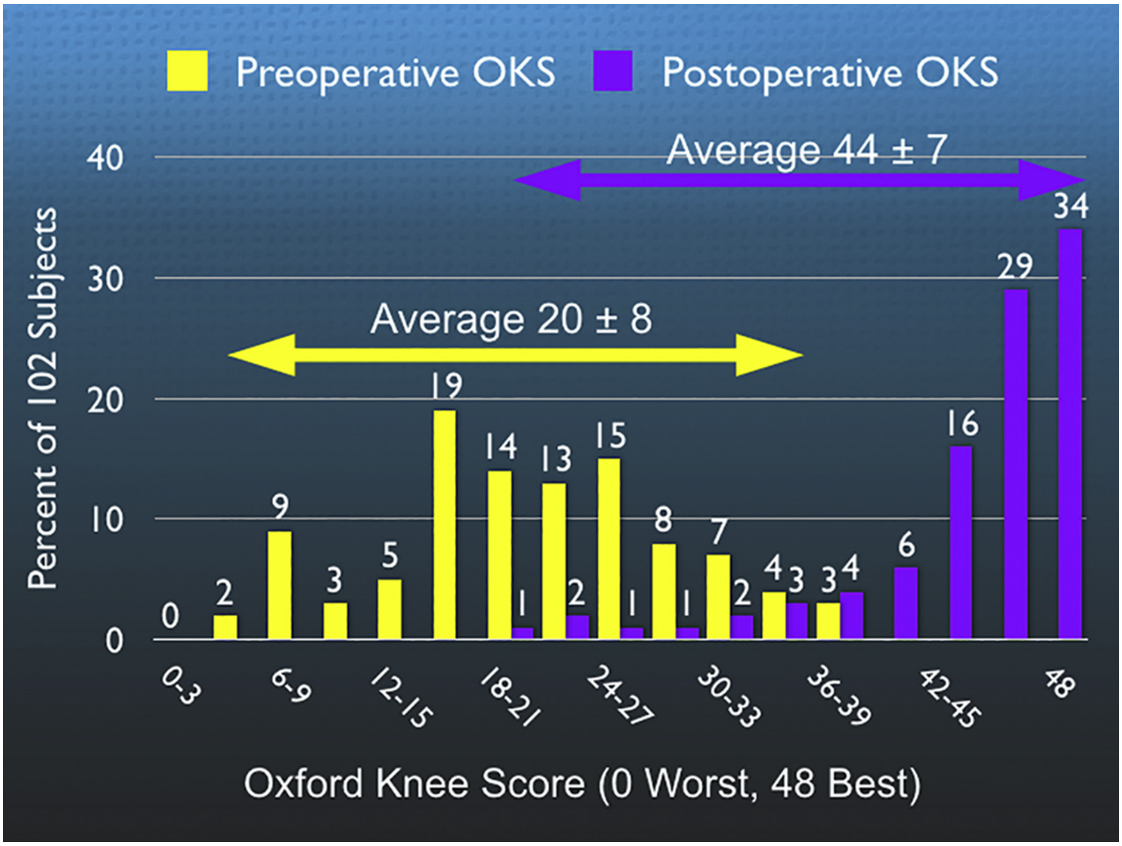

Fig. 6. Column graph shows the mean and range of the preoperative and postoperative self-reported OKSs (48 is best and 0 is worst) for the 102 patients treated with a KA TKA performed with manual instruments. At an average of 15 months postoperatively, 79% had an excellent (>41) and 10% had a good (34-41) OKS. OKA, Oxford Knee Score.

selection bias unlikely (Table 3) [10,11]. Second, the generalizability of the high reliability of restoring the native limb left to right symmetry of the lower limb with the calipered KA technique requires an intersurgeon analysis. Surgeons who use calipers to fine-tune the thickness of the patella resection to within ±1 mm of target possess the skills to perform calipered KA. The calipered KA requires mastering 10 sequential caliper measurements that set the femoral and tibial components coincident with the native femoral and tibial joint lines. On-line surgical videos and an animated surgical technique are free educational resources for learning and practicing the calipered KA technique [38,39]. Third, although posterior cruciate-retaining implants are the preferred implant design for KA, posterior cruciate-sacrificing implants are routinely implanted when the posterior cruciate ligament is torn or inadvertently damaged or detached [12]. No difference in component alignment between posterior cruciate-retaining and substituting implants should be expected [40]. Finally, the descriptive statistics of the alignments of the native leg obtained from patients in Northern California might be different from other ethnic groups such as the Asian population, which has a higher prevalence of varus knees [41].

Two sequential intraoperative quality assurance steps were responsible for restoring the left to right symmetry of the native limb and joint lines in the coronal plane. The first step was the

Table 3
Comparison of Average (±SD) Parameters of Subset of Patients With a Native Limb and a Limb Treated With KA TKA Because of Unilateral Knee Arthritis to all Patients Treated With KA TKA in 3- and 6-y Follow-Up Studies.

Parameters	Unilateral Knee Arthritis (N = 102)	3-y Follow-Up Study (N = 215)	6-y Follow-Up Study (N = 219)	Significance
Clinical characteristics				
Age, y	68 ± 8^{A}	69 ± 10^{A}	74 ± 10^{B}	$P < .0001$
Sex (male), N (%)	49 (48%)	87 (41%)	82 (39%)	NS ($P = .2559$)
Body mass index, kg/m^2	29 ± 5^{A}	$30 \pm 5^{A,B}$	31 ± 6^{B}	$P = .0319$
Preoperative knee condition				
Extension, °	14 ± 8^{A}	8 ± 8^{B}	10 ± 8^{B}	$P < .0001$
Flexion, °	113 ± 8	114 ± 13	113 ± 13	NS ($P = .6809$)
Valgus (−)/varus (+) deformity, °	−1 ± 6	−2 ± 8	−1 ± 6	NS ($P = .1527$)
Function scores				
Preoperative Oxford Knee Score	20 ± 8^{A}	$20 \pm 8^{A,B}$	18 ± 8^{B}	$P = .0200$
Final Oxford Knee Score	44 ± 7	43 ± 7	43 ± 7	NS ($P = .4406$)

For each parameter, means denoted with a different superscript capital letter have a significant difference of $P < .05$.
KA TKA, kinematically aligned total knee arthroplasty; NS, nonsignificant; SD, standard deviation.

caliper measurement and adjustments of the distal femoral resections to match the thickness of the condyles of the femoral component after compensating for cartilage wear and kerf [12,14,42]. The second step was the caliper measurement and adjustments of the medial and lateral tibial condyles at the base of the tibial spines until the varus-valgus laxity with trial components was 1° or less in full extension like the native knee [12,32]. The combination of these 2 steps restored the native left to right symmetry as 95%, 97%, and 97%, respectively, of patients had a difference in the HKA angle, DLFA, and PMTA within ±3° between limbs although the preoperative extension, flexion, and varus-valgus deformities varied widely between knees (Table 1).

Patients and the stewards of global health appreciate a surgical technique associated with a high improvement in function because investigating, treating, and dealing with the painful and poorly functioning TKA is dissatisfying and costly [43]. The present study reported a 24-point improvement and a 44-point average OKS at 15 months for the calipered KA TKA. Two randomized trials comparing KA TKA and MA TKA performed with patient-specific instrumentation reported that the MA group had a 15-point improvement and a 33-point average OKS, and a 20-point improvement and a 41-point average OKS at 2 years [9,13]. A study of the minimally-invasive medial mobile-bearing unicompartmental knee arthroplasty reported a 16-point improvement and 41-point average OKS at 1 and 3 years that was opined as probably better than what would be achieved after MA TKA [44]. These studies suggest that the improvement and average OKS after calipered KA TKA are comparable and potentially better than MA TKA.

Whether calipered KA is equally effective in patients with varus, valgus, and severe preoperative deformities is unknown. A post-hoc analysis showed that the 44-point average postoperative OKS of the 60 patients with preoperative varus deformity and medial wear was not different from the 44-point average postoperative OKS of the 38 patients with preoperative valgus deformity and lateral wear ($P = .7284$). Another analysis showed that patients grouped according to the preoperative Kellgren-Lawrence classification of II, III, and IV had similar 44-point averages for the postoperative OKS ($P = .9107$). Hence, preoperative deformity does not alter postoperative function after calipered KA TKA.

Preoperative factors including function, depression, anxiety, lower socioeconomic status, and errors in surgical technique influence postoperative function and satisfaction as measured by the OKS [45,46]. At 15 months, 11 of the 98 patients in the present study self-reported an average or poor OKS categorized by Kalairajah criterion. The 11 patients had a 16-point average preoperative OKS that was 5 points lower than the 21-point average preoperative OKS of the patients with a postoperative excellent or good OKS ($P < .0382$). A post-hoc analysis showed that the 11 patients had no difference in the angular difference between the KA TKA HKA angle ($P = .2063$), DLFA ($P = .5815$), and PMTA ($P = .1946$) and the native limb from the patients with an excellent or good OKS. Consequently, lower preoperative function likely contributed to the lower postoperative OKS in the 11 patients with a postoperative average or poor OKS.

There are theoretical concerns that patients should not be treated with KA when the preoperative varus-valgus deformities are severe. Five randomized clinical trials comparing KA to MA used no limits or limited the varus-valgus deformity when including patients for treatment with KA. Two randomized clinical trial studies used no limits [9,17], 2 excluded patients with a varus or valgus limit of >10° [8,21], and one excluded patients with a varus or valgus limit of >15° [13]. The 2 randomized trials that used no limits showed greater improvement in pain relief, patient-reported outcomes, and knee flexion in the KA group relative to the MA group [9,17] when compared with those trials that used limits [8,13,21]. One study of Japanese patients, genetically prone to severe varus deformity, used no limits and reported that the KA group had a more parallel joint line orientation relative to the floor during single-leg and double-leg stance than the MA group and a more natural gait [17]. Because studies of KA that used no limits have shown high clinical outcomes [9,17], a joint line parallel to the floor consistent with the native knee [17,28], a negligible risk of varus subsidence of the tibial component at 2-9 years [26], and a low risk of implant failure for any cause up to 6 years [9–11,26], the rationale for excluding patients for treatment with KA based on limits of varus or valgus deformity may be clinically unjustified.

In summary, calipered KA restored native left to right symmetry regardless of the degree of preoperative varus or valgus deformity with a clinically important improvement in patient-reported function.

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