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Primary Knee

Relevance of the Tibial Slope on Functional Outcomes in ACL-Deficient and ACL Intact Fixed-Bearing Medial Unicompartmental Knee Arthroplasty

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ABSTRACT

Background: Excessive posterior tibial slope in medial unicompartmental knee arthroplasty (UKA) has been implicated in early failure. The purpose of this study was to evaluate the relationship between preoperative posterior tibial slope and postoperative slope of the implant (PSI) on outcomes in patients with anterior cruciate ligament (ACL) intact and ACL-deficient knees after fixed-bearing medial UKA.
Methods: Patients who underwent a medial UKA between 2002 and 2017 with a minimum 3-year follow-up were included. Preoperative posterior tibial slope and postoperative PSI were measured. Outcomes measures included Knee Injury and Osteoarthritis Outcomes Score (KOOS) subscales, Lysholm, and VR-12. Failure was defined as conversion to total knee arthroplasty.
Results: Of 241 knees undergoing UKA, 131 patients (70 women, 61 men; average age of 65 $\pm$ 10 years (average BMI of 27.9 $\pm$ 4) were included. For all patients, survivorship was 98% at 5 years and 96% at 10 years with a mean survival time for UKA was 15.2 years [95% CI: 14.6-15.7]. No failure had a PSI $>7^\circ$. There were no superficial or deep infections. There were no significant differences in outcome scores between the ACL intact and the ACL-deficient group; therefore, the data were combined for analysis. At mean 8-year follow-up, KOOS pain scores were better in patients with PSI $\leq 7^\circ$ (87 $\pm$ 16) than those with PSI $>7^\circ$ (81 $\pm$ 15). 76% of patients with PSI $\leq 7^\circ$ reached the Patient Acceptable Symptom State for KOOS pain; whereas, 59% of patients with PSI $>7^\circ$ reached PASS for KOOS pain ($P = .015$).
Conclusion: Patients with postoperative posterior slope of the tibial implant $>7^\circ$ had significantly worse postoperative pain, without conversion to TKA, and with maintenance of high function. In ACL deficient and intact knees, nonrobotically-assisted, fixed-bearing medial UKA had a 96% survivorship at 10 years.

Unicompartmental knee arthroplasty (UKA) is considered an excellent alternative to total knee arthroplasty (TKA) in patients with single compartment knee arthritis [1]. Historically, reasons for failure and revision after UKA have been pain, aseptic loosening, osteoarthritis progression in the opposite compartment, polyethylene wear, instability, pain, and bearing dislocation (in mobile-bearing UKA) [2]. Improvements in implant design and surgical techniques have led to current 10-year UKA survivorship rates. Survivorship after UKA has been reported to be as high as 98% [3–7], rivaling survivorship rates after TKA without the 19% of dissatisfied patients noted after TKA [8].

Proper implant positioning is critical for long-term survivorship of UKA. Malpositioning and alignment can alter the biomechanics of the knee, increasing ligament strain and contact stresses [9–14]. In the absence of ligament stability [15], accurate recreation of the preoperative or anatomic posterior tibial slope is critical to longevity of the UKA. Increased tibial component slope in medial UKA has resulted in degeneration in the lateral compartment,

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abnormal ligament strain, component loosening, and mechanical failure with increased contact stresses [12,13,16–20].

In 2004, Hernigou et al investigated the effect of posterior slope of the implant on long-term outcomes after mobile-bearing medial and lateral UKA in the anterior cruciate ligament (ACL) intact and ACL-deficient knee. Posterior slope of the implant was found to be greater in knees with aseptic loosening. In knees without an ACL who were revised, the posterior slope of the implant was >8° [16]. This seminal study created early guidelines regarding posterior slope of the implant in the ACL intact and ACL-deficient knee for successful outcomes; however, these guidelines were defined based on only seven ACL-deficient knees [16].

Recent work has questioned Hernigou's guidelines regarding posterior slope and ACL deficiency. Chatellard et al. concluded that both posterior slope of the implant >5° and a change in slope >2° from preoperative to postoperative were associated with decreased UKA prosthesis survival [17]. Contrary to this, Boissonneault et al, showed no difference in outcomes between ACL intact and ACL-deficient knees at 5 years with a preoperative slope of 4.7° and a postoperative slope of 2.5° in ACL-deficient knees [15]. Given these data, there is no consensus in the literature in how to proceed in these patients. Furthermore, it is unknown whether posterior tibial slope influences functional outcomes in ACL intact and ACL-deficient knees after UKA.

A uniform technique for measuring tibial slope and tibial slope of the implant does not exist in either the sports medicine or arthroplasty literature for UKA or TKA. In comparing the preoperative posterior tibial slope with the postoperative posterior slope of the tibial implant, one needs a standard method that can be shared with all researchers to measure the slope. Understanding a common, accurate posterior tibial slope calculation will help assist any surgeon to make a more evidence-based decision to predict a favorable outcome for patients.

The purpose of this study was to evaluate the relationship between preoperative posterior tibial slope and postoperative slope of the implant on outcomes in patients with ACL intact and ACL-deficient knees after fixed-bearing medial UKA. Based on previous research which suggests the optimal tibial slope is between 5° [17] and 8° [16], we hypothesized that in the ACL intact or ACL-deficient knee >7° of posterior slope of the tibial implant would not be associated with inferior outcomes and patients would return to an acceptable level of activities after medial UKA using an intermedullary technique in a fixed-bearing implant without robotic assistance.

Materials and Methods

Patient Selection

A total of 241 knees that underwent nonrobotically-assisted, fixed-bearing, UKA (Zimmer Unicompartmental High Flex Knee System (ZUK), Smith & Nephew, Memphis, Tennessee, USA) between 2002 and 2017 by a single surgeon were identified. Patient selection and implantation for UKA were based on the revised criteria proposed by Dunn et al. [21] At the time of implantation, the status of the ACL was evaluated by visual inspection and recorded as intact or ACL deficient. Partial, near complete, and complete ACL tears as well as absent ACLs were included in the ACL-deficient group.

Patients were included in the study if they had a medial UKA, sufficient quality preoperative and postoperative radiographs to measure posterior tibial slope and posterior slope of the implant, and agreed to participate in follow-up. Patients were excluded if they had lateral UKA, inadequate or poor-quality radiographs either preoperatively or postoperatively, refused to participate, or were deceased at minimum 3-year follow-up. (Fig. 1). The remaining 131 UKAs were included in the study. This study was approved by the IRB (Quorum Protocol#33949). Demographic data including age, sex, body mass index, laterality, date of surgery, and follow-up time were collected from an institutional database.

Posterior Tibial Slope and Posterior Slope of the Tibial Implant Measurements

Posterior tibial slope was measured preoperatively and posterior slope of the implant was measured on postoperative plain radiographs obtained within 3 months of surgery by an independent examiner. A true lateral radiograph was obtained in full extension and rotation with complete overlap of the femoral condyles.

To evaluate preoperative tibial slope, a line was drawn passing through the middle of two circles located over the anteroposterior width of the tibia (line a-b) and a second line drawn perpendicular to this line (line a-c) (Fig. 2A). A third line was drawn to connect the most proximal anterior and posterior points of the tibial plateau (inclination of the tibia) (line d-e). The angle between the second and third lines was recorded as the preoperative posterior tibial slope.

To measure the posterior slope of the implant, a line was first drawn on top of the tibial implant (posterior inclination) (line d-e). A second line was drawn perpendicular (line c-d) to the center of tibial axis (a-b) and a third horizontal line was drawn at a 90° to the vertical tibial axis. The angle formed between the first and third lines was recorded as the postoperative slope of the tibial implant (Fig. 2B).

A positive value indicates a posterior tibial slope or posterior sloping implant, and a negative value indicates an anterior tibial slope or anterior sloping implant.

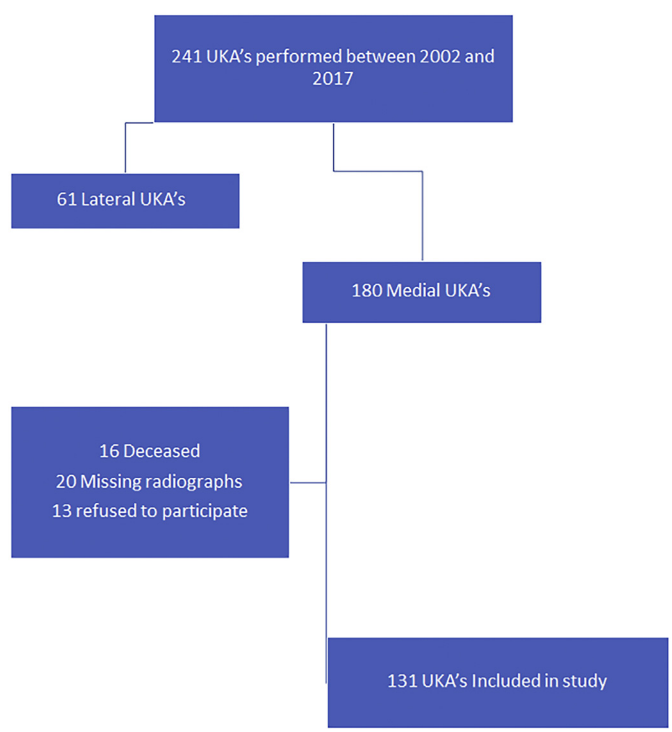

Fig. 1. Diagram showing patient selection for inclusion in the study. The study included patients with medial unicompartmental knee arthroplasty who were not deceased at minimum 3-year follow-up, had postoperative radiographs, and agreed to participate.

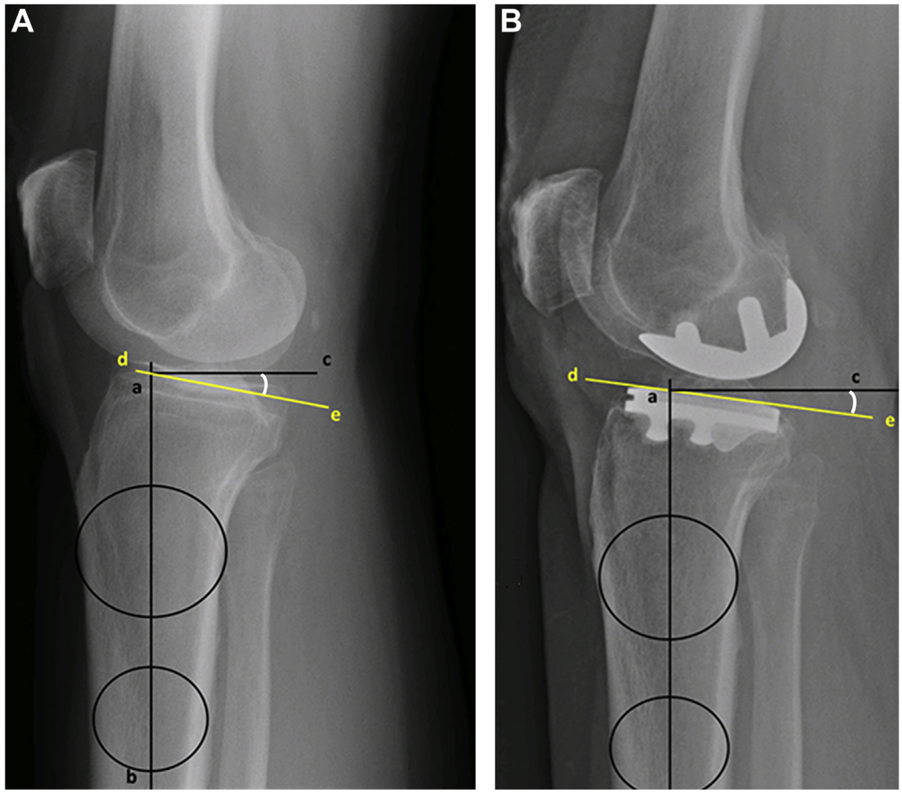

Fig. 2. (A). Radiographs depicting the measurement of preoperative posterior slope in a right knee on a lateral radiograph. A line was drawn passing through the middle of 2 circles located over the anteroposterior width of the tibia (line a-b), and a second line was drawn perpendicular to this line (a-c). The angle between the second line and a line that connects the most proximal anterior and posterior points of the tibial plateau (inclination of the tibial) (d-e) was recorded as the preoperative posterior tibial slope. (B). Radiographs depicting the measurement of postoperative posterior slope of the tibial implant in a right knee on a lateral radiograph. The posterior slope of the implant was the angle between a line drawn on top of the tibial implant (posterior inclination) (d-e) and a line perpendicular (c-d) to the center of tibial axis (a-b). A line was drawn on top of the implant (line d-e) first and then a second horizontal line was drawn with a 90° vertical line. The angle of intersection was then measured. For all measurements, we used the top of the implant to draw the line.

Intrarater and Inter-rater Reliability Measurements

To determine intraobserver reliability, the measurements in 50 knees were repeated one month later by the same orthopedic surgeon. A second, independent observer conducted the measurements on the same 50 knees to determine interobserver reliability.

Outcome Measures

At the most recent follow-up, data collected included clinical examination and patient-reported outcomes. Clinical examination included knee flexion and extension range of motion. Functional outcome scores included Knee Injury and Osteoarthritis Outcomes Score (KOOS) pain subscale; symptom subscale; activities of daily living (ADL) subscale; sport subscale; and Lysholm, Tegner, and the Veterans Rand (VR)-12 physical component score and mental component score. To define successful outcomes in this study, the Patient Acceptable Symptom State (PASS) was used for the KOOS subscales. The PASS thresholds for the KOOS subscales were as follows: KOOS ADL = 87.5, KOOS pain = 87, KOOS symptoms = 84, KOOS quality of life = 66, and KOOS sport = 43.8 [22]. Failures were defined as patients who converted to TKA.

Statistical Analysis

Data are presented as mean ± standard deviation. The one-sample Kolmogorov-Smirnov test was used to test whether variables were normally distributed. Nonparametric univariate analysis was performed with the Mann-Whitney U test for comparison of variables that were not normally distributed. Spearman's ρ correlation coefficient (r) was used to assess associations between continuous variables. The end point was TKA. The Kaplan-Meier method estimates the probability of the proportion of patients with failure at a particular time and can account for patients who have not reached future time points at the time of the analysis.

Results

Study Cohort

Two hundred forty-one patients were identified who underwent UKA. One hundred thirty-one patients (70 women and 61 men) met the inclusion criteria and were included in the study, with an average age of 65 ± 10 years and an average BMI of 27.9 ± 4. No infections were reported in any patient. Of the 131 knees, 99 knees had an intact ACL and 32 were ACL-deficient (Table 1). Of the ACL-deficient knees, twelve knees had a partial, near complete ACL tear, 14 knees had complete ACL tear, and the ACL was absent in 6 knees. There were no significant differences in demographics between the ACL intact and ACL-deficient groups preoperatively.

Posterior Tibial Slope and Posterior Slope of the Tibial Implant

The ICC was 0.990 [98% CI: 0.97-0.996] for intraobserver reliability for preoperative posterior tibial slope. The ICC was 0.70 [98% CI: 0.41-0.81] for interobserver reliability.

Table 1
Comparison of ACL Intact Knees and ACL-Deficient Knees With Mean and Standard Deviation.

Variable	ACL Intact N = 99	ACL-Deficient N = 32	*P*-Value
Age (y)	65 ± 9	65 ± 12	.899
Preoperative posterior tibial slope	5.4 ± 5.9°	7.6 ± 2.8°	.001
Postoperative posterior slope of the tibial implant	5.1 ± 2.6°	5.3 ± 2.4°	.612
Mean postoperative follow-up (y)	7.8 ± 4	8.9 ± 3	.110

Groups were compared using the Mann-Whitney U-test.

Comparisons of the preoperative posterior tibial slope and the postoperative slope of the implant between the ACL-deficient and ACL intact groups are shown in Table 1. The preoperative posterior tibial slope was significantly higher in ACL-deficient knees and the change in slope was significantly greater in the ACL-deficient group ($P = .04$) (Fig. 3). The postoperative posterior slope of the implant was >7° (range 8 to 11°) in 16 knees (15%) in the ACL intact group and 7 knees (22%) (range 8 to 9°) in the ACL-deficient group ($P = .97$).

Conversion to TKA

The combined survivorship for both the ACL intact and ACL-deficient groups was 98% at 5 years and 96% at 10 years. The mean survival time was 15.2 years [95% CI: 14.6-15.7] (Fig. 4). Four of the 131 (3%) patients converted to TKA (Table 2). One patient was ACL deficient. None of the failures had a postoperative slope of the implant >7°, but when analyzed, technical errors in 2 knees and 2 patients had traumatic falls which resulted in TKA.

Outcome Scores

There were no differences in outcome scores between the ACL intact and the ACL-deficient group; therefore, data were combined for analysis (Table 3). At a mean follow-up of 8 years (range 3 to 15), KOOS pain had a significant correlation with posterior slope of the implant ($P = .017$). No other outcomes were correlated with preoperative posterior tibial slope or postoperative posterior slope of the implant (Table 4).

KOOS pain scores at follow-up were lower in patients with ≤7° of postoperative posterior slope of the implant. There were no other differences in KOOS, Lyshom, Tegner, VR-12, or range of motion at follow-up between patients with postoperative posterior slope of the implant of ≤7° or >7° (Table 5). KOOS pain scores were lower in patients with ≤7° of postoperative posterior slope of the implant ($P = .046$). Seventy-one percent of patients in ≤7° of postoperative posterior slope of the implant reached PASS for KOOS pain while only 59% in the >7° group reached PASS for KOOS pain ($P = .015$). Eighty-one percent of patients with ≤7° postoperative posterior slope of the implant reached PASS for KOOS ADL and 73% reached PASS for KOOS sport, which was higher than the >7° group, but this did not reach statistical significance. There were no other significant differences in the percentage of patients who reached PASS for the other KOOS subscales between patients with >7° or ≤7° posterior slope of the implant.

Discussion

Posterior tibial slope has been implicated in failure of UKA due to alterations in knee biomechanics and implant failure. We investigated the role of posterior tibial slope on outcomes in medial compartment UKA in ACL intact and ACL-deficient knees. While ACL-deficient knees had greater posterior tibial slope at the time of UKA and a greater change in slope, there was no difference in postoperative slope of the implant or outcomes compared with ACL intact knees. KOOS pain was associated with a posterior slope of the implant with higher scores in patients with >7°. Furthermore, a higher percentage of patients reached PASS for KOOS pain with a posterior slope of the implant ≤7°.

Intermedullary femoral alignment guides and extramedullary tibial alignment guides and jigs were used to attempt to reproduce the anatomic posterior tibial slope. The ZUK implant is designed for an anatomic position with a 5° postoperative posterior slope of the tibial implant. While adjustments to the posterior tibial slope can be made intraoperatively, the use of these well-designed instruments help to guide the surgeon to a predictable outcome which might explain the preponderance of postoperative posterior slope of the implant equal to or less than 7° in this series of fixed-bearing, nonrobotically-assisted UKA series; however, the 7° cutoff value was chosen based on previous studies which suggest the optimal tibial slope is between 5° [17] and 8° [16].

A higher posterior tibial slope of the implant has been implicated in greater anterior tibial translation particularly in the ACL-deficient UKA [16]. In a computer simulation model, Sekiguchi et al demonstrated greater ACL tension with increasing posterior tibial slope values. In addition, they reported increased medial-lateral translation and increased anteroposterior position with increasing posterior slope during deep knee bending and gait simulations with a fixed-bearing UKA [13]. These findings suggest a posterior tibial slope of 3° to 7° to limit stress on the ACL [13].

In the present study, a postoperative posterior tibial slope of the implant of ≤7° was associated with better KOOS pain scores; however, KOOS ADL, sport, or QOL scores were not associated with posterior slope of the implant in either ACL intact or ACL-deficient knees. ACL-deficient knees had higher preoperative posterior tibial slope, which resulted in a greater change in slope; however, this did not affect outcomes in the ACL-deficient medial UKA. All knees had postoperative posterior tibial slope values ranged −3 to 11°, with 85% of values ≤ 7°. We did not observe in this cohort of 131 knees any large postoperative posterior slope of the final tibial implant (13 to 18°) which Hernigou suggested avoiding to protect the ligaments from degeneration [16]. The authors would consider a preoperative posterior slope of 13° to 18° a contraindication to UKA and in most cases recommend proceeding with a TKA, highlighting the importance of accurate measurement of the preoperative posterior tibial slope.

While ACL-deficient knees were an exclusion criteria as described by Kozin et al, [23] several recent studies have shown success after UKA implanted in ACL-deficient knees with postoperative posterior tibial implant slopes ranging from 5-8° [15,24–26]. In the present study, with fixed-bearing cemented implants, ACL deficiency was not associated with conversion to TKA at mean survivorship of 15.2 years. A recent report in 2021 from Veizi et al reported that posterior slope of the implant increased over time in mobile-bearing UKAs [27]. This article though included a small sample of only 31 patients at 2 years and 22 patients with 5 years or greater follow-up. We have not found this to be the case in fixed-bearing UKA in our series.

Previous studies have reported postoperative posterior slope of the implant as a factor associated with early revision [16–18,28]. In the ACL-deficient knee, excessive postoperative posterior slope of the implant may over time create greater stresses on the implant, which is of greater importance in the mobile-bearing implant. Kazarian and Barrack, et al, identified malalignment, slope, and overhang as significant risk factors for failure or revision [19]. They defined outliers for slope at 7° ± 5°, with far outliers equal to an additional ±2°. Failure rate was significantly impacted by tibial

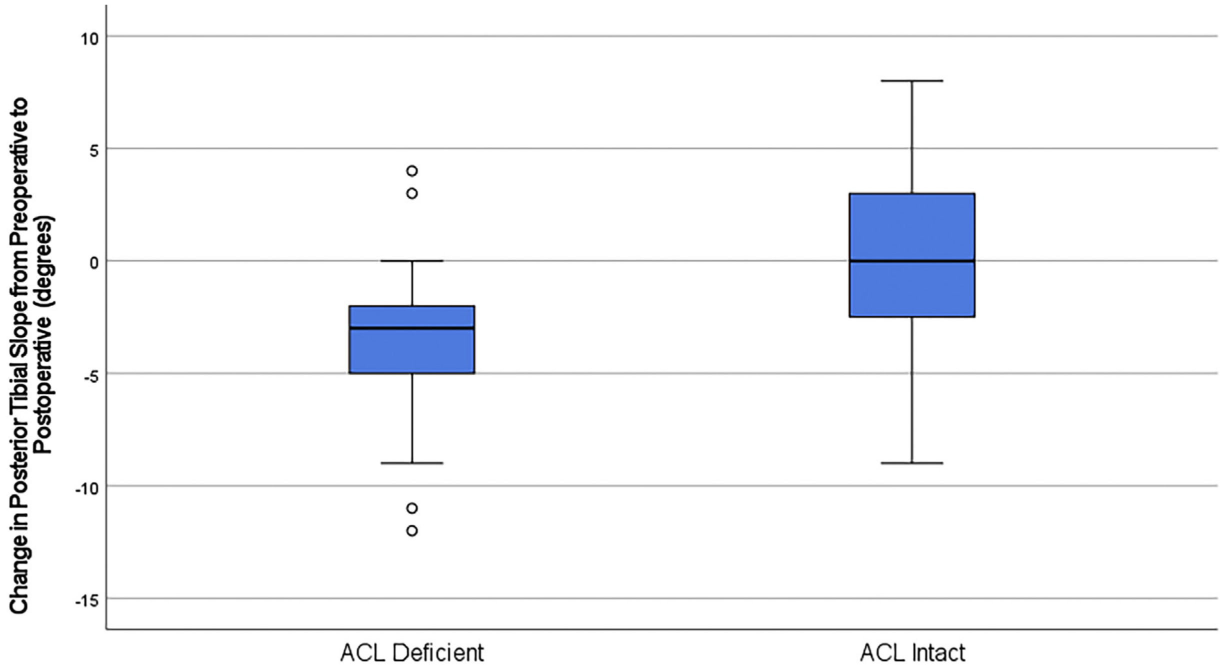

Fig. 3. The graph depicts changes in slope between the ACL-deficient group and the ACL intact group. The ACL-deficient knees had a significantly higher preoperative slope than ACL intact knees, which led to a greater decrease in preoperative slope.

slope outliers, and even greater failures were seen with far outliers. The authors found no differences between fixed and mobile-bearing implants with regards to failures or radiographic outliers; however, individual analysis of each measurement was not compared between the groups [19]. It is unclear if the risk of failure associated with malalignment, overhang, and posterior slope is different based on the type of implant. While our study did include some outliers, far outliers were limited due to the selection criteria mentioned previously. A preoperative posterior slope of 13° to 18° degrees was a relative contraindication for UKA, which limits our ability to comment on far outliers. These selection criteria may also be reflected in the low failure rate in our cohort. Hernigou et al suggested a postoperative posterior slope of the implant >8° be avoided in UKA, and Franz recommended that the slope be

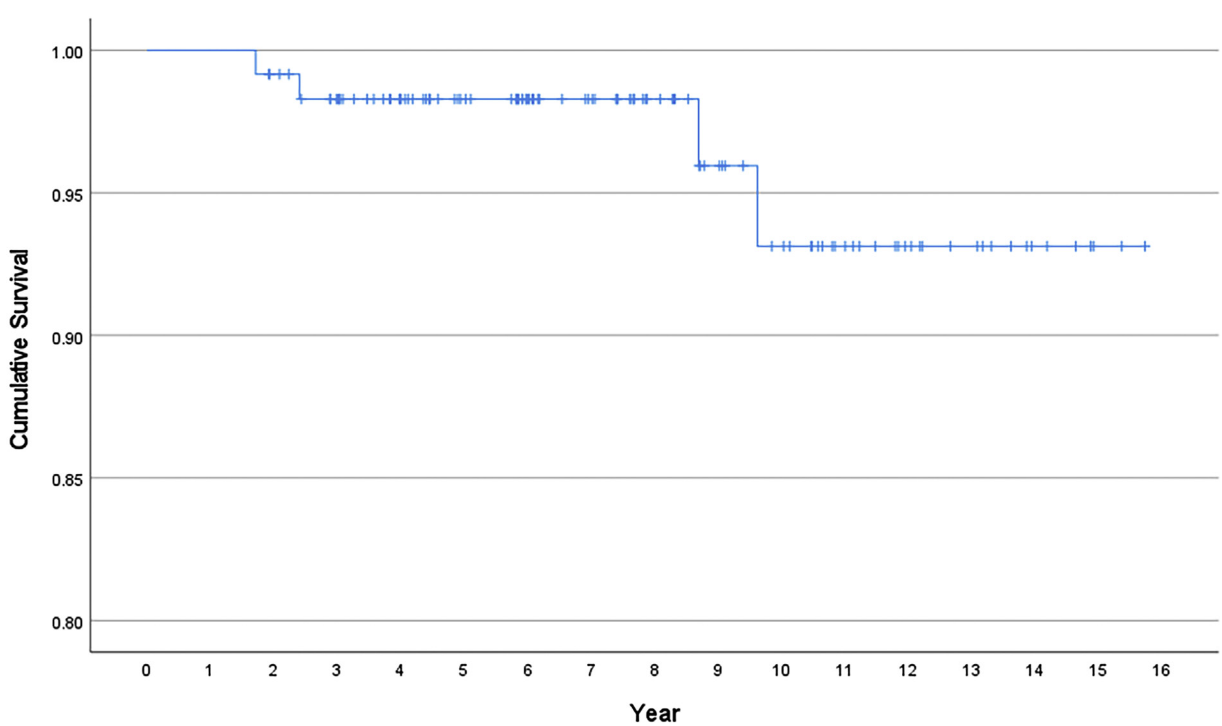

Fig. 4. Kaplan-Meir survivorship curve showing survivorship annually up to 15 years for all patients in the study. Survivorship was 98% at 5 years and 96% at 10 years.

Table 2
Failed UKA Revised to TKA.

Patient	Years to TKA	ACL	Reason for Failure	Preoperative Posterior Tibial Slope (Degrees)	Postoperative Slope of the Implant (Degrees)	Age at Surgery (Y)	Gender	BMI
1	2	Intact	Technical error	8°	7°	60	F	40.7
2	2.5	Intact	Technical error	8°	5°	63	F	23.4
3	9	Intact	Trauma	6°	6°	59	F	40.0
4	10.5	Deficient	Trauma	9°	6°	74	F	18.8

TKA, total knee arthroplasty; ACL, anterior cruciate ligament; BMI, body mass index.

reconstructed within “acceptable ranges” of the preoperative posterior tibial slope [16,18]. Our findings are consistent with Hernigou and suggest a postoperative posterior slope of the implant >7° may result in persistent pain after medial UKA.

In this study, survivorship of 98% at 5 years and 96% at 10 years in fixed-bearing UKA is now approaching the reported survivorship of TKAs in Medicare data (96%) [1]. Ten years ago, Bruni et al [3] reported 87.6% survivorship at 10 years, while Franz et al [18] most recently reported 90% at 4 years. Medicare population data reported a 7-year survival rate for UKA of 81% [1]. Kazarian and Barrack reported 88% survivorship of UKAs at 5 years and 70% at 10 years; however, this was a combination of mobile and fixed-bearing UKA implants [19]. Our survivorship at 10 years was much higher (95%) than those previously reported, yet equivalent to TKA 10-year survivorship [1].

It is also important to note that 81% of patients reached PASS for KOOS ADL and 73% achieved PASS for KOOS sports. In this study, the fixed-bearing medial UKA allowed patients to return to activities. Return to physical activity plays an important role in the prevention cardiovascular disease, obesity, type 2 diabetes, hypertension, osteoporosis, and depression [29]. Jansen et al showed that compared with TKA, patients with UKA had higher activity level and greater satisfaction [30]. This increase in activity does not increase the risk of revision after UKA [31]. The ability to continue physical activity may lessen age-related decline. With this knowledge, it should be the goal of all procedures to improve physical activity in patients after arthroplasty.

Limitations of this study include the knowledge of variability that exists in posterior slope measurements in the literature, whether with radiographs, MRI, or CT [32–37]. Average native medial and lateral tibial slopes have been reported to be 5.7 ± 3.8° and 5.6 ± 4.1°, respectively [32]. Koh et al reported an average medial posterior tibial slope of 10.4 ± 4° using 3-D MRI [34]. Gwinner et al reported significantly smaller posterior tibial slope measurements on MRI than radiographs [32]. In our cohort of 131 knees, an independent musculoskeletal fellowship-trained radiologist measured the posterior tibial slope on MRI in 50 knees. Slope on MRI was significantly lower than slope measured on radiographs (2 ± 3° vs. 6.5 ± 3°; $P < .01$). Posterior tibial slope has also been measured using CT scans with a similar degree of variability. One study reported an average of 11° and a reference range of 5° to 17° in normal knees on 3D-CT [35], while another reported an average posterior tibial slope of 6.3° on CT [37]. Another study by Meier et al measured posterior tibial slope on CT in 15,807 patients and found the majority had a posterior tibial slope between 5° and 10°, confirming the large range of the posterior tibial slope [36].

Lack of agreement is evident in the literature when reporting preoperative and postoperative tibial slope. We recommend a standard method using plain radiographs to evaluate preoperative and postoperative tibial slope. We describe a defined technique for the fixed-bearing UKA to measure preoperative and postoperative slope on standard plain film radiographs. Our intraobserver and interobserver reliability was in the appropriate range. Other authors have suggested drawing the line at either the top of the implant, the middle of the implant, or the level of the bone when measuring postoperative tibial slope of the implant. The vertical line of measurement has also come into question as some draw it down the anterior tibial cortex and others down either the posterior cortex or the middle of the tibia (Table 6). It is unclear how different implants and the line of measurement may affect slope measurements; however, with no definite standard, it is difficult to compare studies and come to a consensus on a postoperative slope of the implant range which data could be used by clinicians to suggest to patients appropriate or more predictable outcomes. This method provides for an accurate posterior tibial slope calculation to allow us to make a more evidence-based decision to predict outcomes for patients.

We further realize the large standard deviation of measurements of posterior slope in the literature ranging from 3° to 4° [38,39]. This standard deviation could lead to measurements falling on either side of the 7° threshold based on measurement error. A study using a large number of patients, such as a registry which includes evaluation of posterior tibial slope, could further define a prediction model that includes posterior tibial slope, working toward conclusive evidence-based surgical indications.

Table 3
Comparisons of Outcomes at Follow-Up Between Patients With an ACL Intact Knee and ACL-Deficient Knee.

Variable	ACL Intact N = 96	ACL Deficient N = 31	*P*-Value
VR-12 PCS	56 ± 7	57 ± 8	.282
VR-12 MCS	54 ± 5	53 ± 4	.212
KOOS pain	86 ± 17	88 ± 11	.800
KOOS Symptom	67 ± 12	72 ± 17	.139
KOOS-ADL	88 ± 15	93 ± 7	.238
KOOS-sport	63 ± 33	71 ± 29	.283
KOOS-QOL	81 ± 16	78 ± 15	.428
Lysholm	83 ± 19	87 ± 17	.391

There were no significant differences between groups in any outcome measure. Groups were compared using the Mann-Whitney U-test for comparison of means.

Table 4
Correlations of Preoperative Posterior Tibial Slope and Postoperative Posterior Slope of the Implant With Follow-Up Outcome Variables.

Variable	Preoperative Posterior Tibial Slope (Rho)		Postoperative Slope of the Implant (Rho)	
	Rho	*P*-Value	Rho	*P*-Value
VR12 MCS	−0.081	.416	−0.054	.587
VR12 PCS	0.19	.846	0.100	.309
KOOS pain	0.005	.961	−0.229	.017[a]
KOOS symptoms	0.37	.704	−0.11	.908
KOOS ADL	0.098	.319	−0.143	.142
KOOS sport	−0.058	.552	0.14	.886
KOOS QOL	0.072	.470	0.064	.803
Lysholm	−0.051	.591	−0.024	.803
Tegner	0.140	.210	−0.007	.953

[a] Significant correlations. Continuous variables compared using Spearman’s correlation coefficient rho.

Table 5
Comparisons of Outcomes at Follow-Up Between Postoperative Posterior Slope of the Implant ≤7° and >7°.

Variable	≤7° Postoperative Posterior Slope of the Implant N = 108	>7° Postoperative Posterior Slope of the Implant N = 19	*P*-Value[a] (*P*-Value for Comparison Between % of Patients Who Reach PASS)
Mean extension (°)			
Preoperative	1.5 ± 3.5	2.6 ± 4.7	.337
Postoperative	0.48 ± 2	1.0 ± 3	.208
Mean flexion (°)			
Preoperative	123 ± 13	124 ± 9	.803
Postoperative	129 ± 11	129 ± 8	.843
VR-12 PCS	55 ± 8	57 ± 8	.312
VR-12 MCS	54 ± 5	54 ± 5	.303
KOOS pain	87 ± 16 (71%)	81 ± 15 (59%)	.046[a] (.015[a])
KOOS symptom	67 ± 15 (30%)	68 ± 12 (20%)	.542 (.897)
KOOS-ADL	89 ± 14 (81%)	88 ± 14 (70%)	.166 (.665)
KOOS-sport	61 ± 33 (73%)	65 ± 25 (65%)	.651 (.498)
KOOS-QOL	81 ± 16 (86%)	78 ± 15 (82%)	.461 (.665)
Lysholm	83 ± 19	87 ± 18	.376

All values are mean ± standard deviation (% patients attained PASS).
[a] Groups were compared using the Mann-Whitney U-test for comparison of means and chi square for comparison of percentage of patients reaching PASS.

Another limitation of this study is the sample size in a single surgeon, single implant study. While similar studies have been performed using large databases or multicenter studies, this study reveals the safety for a mid-volume surgeon to be confident, when skilled and trained, to perform this procedure to yield long-term survival of 96% at 10 years. We recognize the importance of the learning curve with the noted small number of failures and conversions to TKA. Of the 4 patients who required TKA, 2 patients had their procedure in the first 10 cases of the series with had technical errors performed of overstuffing, created failure in the lateral compartment, while the other 2 patients who failed had traumatic falls at 9 and 10 years. The steep learning curve for surgeons in UKAs still exists and we advise obtaining as much training as possible before undertaking this procedure without a robot.

In conclusion, preoperative posterior tibial slope and postoperative posterior slope of the implant were not associated with failure or decreased functional outcomes after nonrobotically-assisted, fixed-bearing medial UKA in a series of ACL intact and ACL-deficient knees. Higher KOOS pain scores were seen in patients with a postoperative posterior slope of the implant >7°; however,

Table 6
Literature Measuring Postoperative Posterior Slope of the Implant After UKA.

Author	Journal	Description of Measurement
Boissonneault et al [15]	Knee Surg Sports Traumatol Arthrosc. 2013; 21:2480-6.	Vertical Line: Line drawn along the posterior border of the diaphysis of the tibia. Tibial slope line: Line drawn through the anterior and posterior margins of the native tibial plateau.
Takayama et al. [42]	Knee 2016; 23:517-522	The posterior tibial slope was measured with reference to the sagittal axis, which was defined as the line connecting the midpoints of the medial tibia plateau and the tibia plafond.
Hernigou et al. [16]	J Bone J Surg Am. 2004; 86:506–511	Vertical line: Line along the posterior tibial cortex. Tibial slope line: Posterior inclination of the tibial implant.
Bruni et al. [3]	Knee Surg Sports Traumatol Arthrosc. 2010;18:710-717	Vertical Line: The tibial anatomical axis. Tibial slope line: Line passing through the largest number as possible of points on the medial tibial plateau.
Chatellard et al. [17]	Orthop Traumatol. 2013; 99S:S219-S225	Tibial slope line: Line connecting the anterior and posterior rims of the medial tibial plateau preoperatively and postoperatively, the tangent to the tibial component.
Franz et al. [18]	J Knee Surg. 2019;32:468-474	Vertical: Line perpendicular to the TPAA axis. Tibial slope line: posterior inclination of the medial tibial plateau.
Seo et al [40]	Knee Surg Relat Res 2013; 25:25-29	Vertical Line: Line proximal to the tibia anterior cortex. Tibial slope line: Tibial plateau line.
Veizi et al [29]	J Arthoplasty 2020; SO883-5403:31,301-2	Vertical Line: Line passing through 2 points located in the center of the anteroposterior width of the tibia at 5 and 10 cm apart from the proximal diaphysis. Tibial slope line: Line of the medial plateau.
Shelbourne [41]	Am J Sports Med. 2021;49:620-625	To measure posterior tibial slope (PTS), intersecting lines were drawn along the medial tibial plateau and the posterior tibia. The value of the acute angle at the lines' intersection was 82, which was then subtracted from 90 to obtain the PTS value of 8.

overall 10-year survival rate was 96% with high KOOS function, ADL, and sport subscores in both ACL intact and ACL-deficient cohorts. We suggest our uniform method of measuring the posterior tibial slope to guide future research in developing evidence-based surgical indications and improved outcomes.

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