Cureus
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Open Access Original Article

Early Survivorship and Clinical Outcomes Following Cementless Robotic-Assisted Restricted Kinematic Alignment Total Knee Arthroplasty

Review began 10/30/2026
Review ended 11/03/2026
Published 11/10/2026

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DOI: 10.7759/cureus.119433

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Abstract

Background and objective: Kinematic alignment (KA) has gained interest in total knee arthroplasty (TKA) because of its potential to restore native knee anatomy and improve patient outcomes. Robotic-assisted TKA has been adopted to enhance the precision and reproducibility of component positioning. The purpose of this study was to evaluate early survivorship and clinical outcomes following cementless robotic-assisted restricted KA TKA.

Methods: A retrospective review was performed of consecutive patients undergoing primary cementless robotic-assisted KA TKA by a single fellowship-trained arthroplasty surgeon between May 2024 and June 2025. Patients with a minimum one-year follow-up were included. A restricted KA philosophy with predefined alignment boundaries was utilized. The primary outcome was survivorship free from aseptic revision. Secondary outcomes included all-cause revision, reoperations, manipulation under anesthesia (MUA), patient-reported outcomes, and radiographic alignment distribution.

Results: A total of 100 cementless robotic-assisted KA TKAs were included. Survivorship free from aseptic revision was 100% at a mean follow-up of 22.8±3.2 months, with no cases of aseptic loosening. The Patient-Reported Outcomes Measurement Information System (PROMIS) physical function increased by 8.0±9.1 points, PROMIS pain interference decreased by 11.5±10.9 points, and PROMIS mobility increased by 9.8±8.8 points from baseline. The mean postoperative Forgotten Joint Score (FJS) was 66.0±26.7, and patient satisfaction was 3.6 ± 0.6 on a four-point Likert scale. The MUA was performed in 6% of knees. Postoperative radiographs demonstrated a broad coronal and sagittal alignment distribution consistent with KA principles.

Conclusions: Cementless robotic-assisted KA TKA demonstrated excellent early survivorship and favorable patient-reported outcomes at short-term follow-up. Robotic assistance facilitated consistent execution of KA principles while achieving patient-specific alignment targets, supporting the early compatibility of restricted KA with contemporary cementless fixation.

Categories: Orthopedics
Keywords: cementless total knee arthroplasty, kinematic alignment, patient-reported outcome, robotic assistance, survivorship

Introduction

Total knee arthroplasty (TKA) has traditionally been performed using mechanical alignment (MA) principles with the goal of achieving a neutral limb axis [1]. More recently, interest in patient-specific alignment strategies, including kinematic alignment (KA), has increased because of the potential to better individualize component positioning while minimizing soft tissue releases and preserving more physiologic knee balance [2,3]. Concurrently, robotic-assisted TKA has gained widespread adoption because of its ability to improve the precision and reproducibility of component positioning while facilitating intraoperative assessment of alignment and soft tissue balance [4-8].

Cementless fixation in TKA has similarly experienced renewed interest, particularly in younger and more active patient populations, because of advances in implant design and biologic fixation surfaces [9,10]. However, limited data exist evaluating the early clinical outcomes and survivorship of cementless robotic-assisted KA TKA. Additionally, concerns remain regarding the effect of patient-specific alignment strategies on implant fixation durability and reproducibility of alignment execution.

The purpose of this study was to evaluate early survivorship, complications, patient-reported outcomes, and radiographic alignment distribution following cementless robotic-assisted KA TKA performed utilizing restricted alignment targets by a single fellowship-trained arthroplasty surgeon. We hypothesized that cementless robotic-assisted KA TKA would demonstrate excellent early survivorship and favorable patient-reported outcomes at short-term follow-up.

How to cite this article
Hollenberg A M, McCoy L H, Brown N M, et al. (November 10, 2026) Early Survivorship and Clinical Outcomes Following Cementless Robotic-Assisted Restricted Kinematic Alignment Total Knee Arthroplasty. Cureus 18(11): e119433. DOI 10.7759/cureus.119433

Materials And Methods

Study design

Following approval from the Washington University in St. Louis Institutional Review Board (approval no.202408089), a retrospective review of consecutive primary cementless robotic-assisted KA TKAs performed by a single fellowship-trained arthroplasty surgeon between May 1, 2024, and June 1, 2025, was conducted. Patients with a minimum one-year clinical follow-up were included. Patients who underwent revision arthroplasty, simultaneous bilateral procedures, TKA for inflammatory or post-traumatic arthritis, or incomplete clinical follow-up were excluded from analysis. Demographic and clinical variables were collected from the electronic medical record.

Clinical outcomes

The primary clinical outcome was survivorship free from aseptic revision. Secondary outcomes included all-cause revision, reoperations, manipulation under anesthesia (MUA), and postoperative complications. Patient-reported outcome measures collected preoperatively and postoperatively included the Patient-Reported Outcomes Measurement Information System (PROMIS) physical function (PF), PROMIS pain interference (PI), and PROMIS mobility [11]. The Forgotten Joint Score (FJS) and patient satisfaction were collected postoperatively [12]. Patient satisfaction was assessed using a four-point Likert scale, with higher scores indicating greater satisfaction [13].

Radiographic analysis

Radiographic analysis was performed using standardized standing anteroposterior and lateral knee radiographs. Alignment measurements were performed for all patients and included the tibiofemoral angle (TFA), anatomic lateral distal femoral angle (aLDFA), anatomic medial proximal tibial angle (aMPTA), joint line convergence angle (JLCA), and tibial slope. Measurements are reported in degrees (°). Negative values indicate valgus alignment. Assessment of radiographic fixation was based on final postoperative radiographs and included evaluation of radiolucent lines, component subsidence or migration, or evidence of aseptic loosening or implant failure.

Surgical technique

All procedures were performed using a previously described technique for robotic-assisted KA TKA [14]. A restricted KA philosophy was used with the goal of restoring native joint line orientation and constitutional limb alignment. Coronal alignment targets were planned within 6° of varus and 3° of valgus relative to the mechanical axis. In the sagittal plane, the posterior tibial slope was individualized to approximate native anatomy with a maximum target slope of 10°.

Preoperative CT planning and intraoperative cartilage mapping were used to account for patient-specific anatomy, including cartilage thickness and wear, allowing bone resections to be adjusted according to KA principles. Femoral component flexion was selected to best recreate native femoral anatomy while avoiding anterior femoral cortex notching. Component positioning aimed to achieve a relatively rectangular extension gap and a physiologic trapezoidal flexion gap with variable lateral laxity while minimizing soft tissue releases. The robotic platform (Mako SmartRobotics; Stryker, Mahwah, NJ, USA) was utilized for preoperative planning, intraoperative assessment of soft tissue balance, and execution of planned bone resections (Figure *1*).

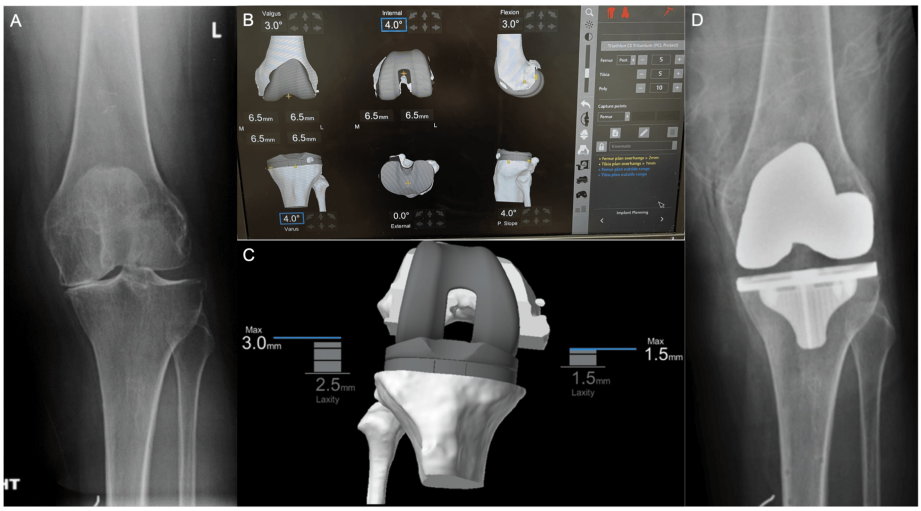


FIGURE 1: Representative case demonstrating cementless robotic-assisted restricted KA TKA utilizing individualized coronal and sagittal alignment targets

A: Preoperative standing anteroposterior (AP) radiograph demonstrating constitutional coronal varus deformity; B: CT-based robotic preoperative planning demonstrating individualized femoral and tibial component positioning within predefined coronal and sagittal alignment boundaries; C: Intraoperative robotic gap assessment demonstrating a physiologic trapezoidal flexion gap with variable lateral laxity; D: Postoperative standing radiograph demonstrating restoration of patient-specific coronal alignment following cementless cruciate-retaining TKA

KA: Kinematic alignment, TKA: Total knee arthroplasty

All procedures were performed utilizing a cruciate-retaining femoral component (Triathlon; Stryker, Mahwah, NJ, USA) with preservation of the posterior cruciate ligament and a condylar-stabilized polyethylene insert. Cementless fixation was used based on subjective intraoperative assessment of bone quality without strict age- or sex-based selection criteria.

Statistical analysis

Continuous variables are reported as means and standard deviations, while categorical variables are reported as frequencies and percentages. Continuous variables were compared using independent and paired t-tests, while categorical variables were analyzed using chi-square or Fisher exact testing, as appropriate. Survivorship free from aseptic revision was evaluated using Kaplan-Meier analysis. Based on previously published literature, the minimal clinically important difference (MCID) used for PROMIS PF and PI was 11.3 and 8.9, respectively [15]. Statistical significance was defined as $p < 0.05$. All analyses were performed using GraphPad Prism version 11.0 (GraphPad Software Inc., San Diego, CA, USA).

Results

Patient characteristics

A total of 100 consecutive cementless robotic-assisted KA TKAs met the inclusion criteria (Table *1*). Female patients comprised 50% (n = 50) of the cohort. The mean age at the time of surgery was 64.7 ± 8.7 years, with a mean BMI of 31.9 ± 5.9 kg/m² and a mean Charlson comorbidity index (CCI) of 4.1 ± 2.1. Regarding insurance status, 42% (n = 42) of patients were covered by Medicare, and 59% (n = 59) had private insurance. The mean postoperative follow-up duration was 22.8 ± 3.2 months.

Variable		Value
Total knees, n		100
Female sex, n (%)		50 (50)
Age, years		64.7 ± 8.7
BMI, kg/m²		31.9 ± 5.9
CCI		4.1 ± 2.1
Insurance, n (%)	Medicare	42 (42)
	Private	59 (59)

TABLE 1: Patient demographics

Data are presented as means ± standard deviations or frequencies (percentages); CCI: Charlson comorbidity index

Survivorship and complications

Survivorship free from aseptic revision was 100% (n = 100) at the final follow-up (Table *2*). No cases of radiographic aseptic loosening were identified during the study period. Manipulation under anesthesia for postoperative stiffness was performed in six knees (6%) at a mean of 55.5 ± 6.7 days following the index procedure. One reoperation was recorded: irrigation and debridement with polyethylene exchange for superficial wound dehiscence and hematoma evacuation.

Outcome	Value
Survivorship free from aseptic revision, n (%)	100 (100)
Aseptic loosening, n (%)	0 (0)
Reoperations, n (%)	1 (1)
MUA, n (%)	6 (6)

TABLE 2: Survivorship and complications

Data are presented as frequencies (percentages); MUA: Manipulation under anesthesia

Patient-reported outcomes

Patient-reported outcomes are summarized in Table *3*. Preoperative and postoperative PROMIS scores were available for 57% (n = 57) of patients. In this subgroup, PROMIS PF increased by 8.0 ± 9.1 points, PROMIS PI decreased by 11.5 ± 10.9 points, and PROMIS mobility increased by 9.8 ± 8.8 points from baseline. Clinically meaningful improvement was achieved in 33.3% (n = 19) and 50.9% (n = 29) of patients for PROMIS PF and PROMIS PI, respectively. Postoperative FJS and patient satisfaction data were available for the entire cohort. The mean FJS at final follow-up was 66.0 ± 26.7. Mean patient satisfaction was 3.6 ± 0.6 on a four-point Likert scale, with 95% (n = 95) of patients reporting either 'satisfied' or 'very satisfied.'

Outcome	Preoperative mean ± SD	Postoperative mean ± SD	Δ	p-value	Test statistic	MCID achievement
PROMIS PF (n = 57)	37.9 ± 5.4	45.9 ± 9.4	8.0 ± 9.1	<0.001	6.60	33.3% (n = 19)
PROMIS PI (n = 57)	64.0 ± 5.3	52.5 ± 10.6	-11.5 ± 10.9	<0.001	7.98	50.9% (n = 29)
PROMIS mobility (n = 57)	36.4 ± 4.6	46.1 ± 9.5	9.8 ± 8.8	<0.001	7.57	-
FJS (n = 100)	-	66.0 ± 26.7	-	-		-
Patient satisfaction (n = 100)	-	3.6 ± 0.6	-	-		-

TABLE 3: Patient-reported outcomes

Data are presented as means ± standard deviations. The data were analyzed with a paired t-test. A p-value < 0.05 was considered statistically significant.

Δ: Preoperative to postoperative change, MCID: Minimal clinically important difference, PROMIS: Patient-reported outcomes measurement information system; PF: Physical function; PI: Pain interference; FJS: Forgotten joint score

Radiographic outcomes

Postoperative radiographic analysis demonstrated a broad alignment distribution consistent with restricted KA philosophy while generally remaining within predefined coronal and sagittal alignment targets (Figure *2*). The mean TFA changed from 1.2 ± 4.4° preoperatively to -3.3 ± 2.4° postoperatively (t = 11.43, p < 0.001; Table *4*). The mean aMPTA was 85.6 ± 1.9° preoperatively and 85.1 ± 1.8° postoperatively (t = 2.38, p < 0.09), while the mean aLDFA decreased from 82.6 ± 2.0° to 81.8 ± 1.9° (t = 4.23, p = 0.004). The mean posterior tibial slope was 6.2 ± 2.3° preoperatively and 5.7 ± 2.1° postoperatively (t = 1.71, p = 0.09). The mean preoperative JLCA was 3.9 ± 2.4°. Overall, 80% of patients maintained their native coronal joint line orientation within 2° of baseline following surgery, demonstrating reproducible restoration of patient-specific coronal anatomy.

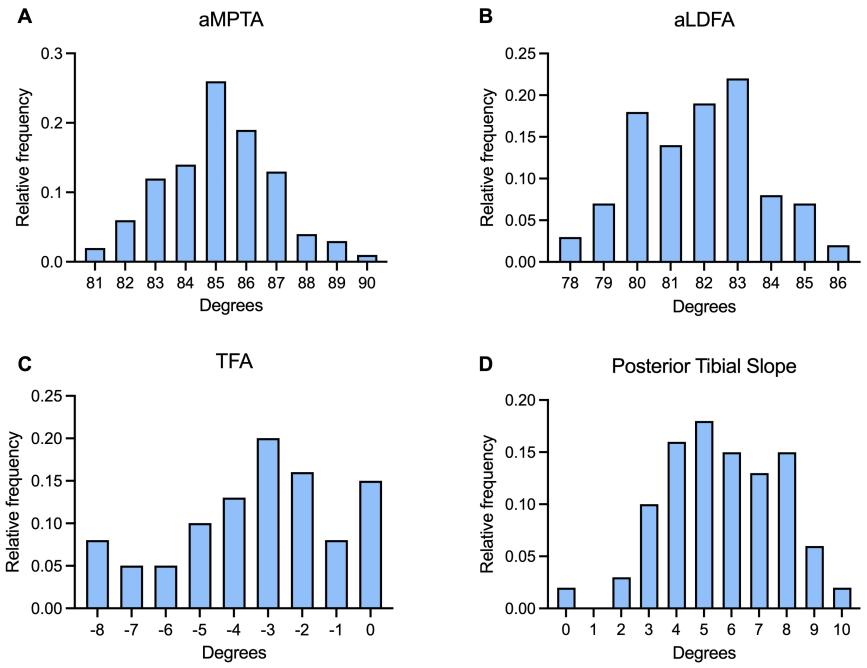


FIGURE 2: Histograms demonstrating postoperative coronal and sagittal alignment distributions following cementless robotic-assisted restricted KA TKA

Postoperative alignment demonstrated a broad distribution consistent with KA principles while generally remaining within intended coronal and sagittal alignment targets. Distribution histograms are shown for postoperative aMPTA (A), aLDFA (B), TFA (C), and posterior tibial slope (D).

KA: Kinematic alignment, TKA: Total knee arthroplasty, aMPTA: Anatomic medial proximal tibial angle, aLDFA: Anatomic lateral distal femoral angle, TFA: Tibiofemoral angle

Variable	Preoperative mean ± SD	Postoperative mean ± SD	p-value	Test statistic
TFA (°)	1.2 ± 4.4	-3.3 ± 2.4	<0.001	11.43
aMPTA (°)	85.6 ± 1.9	85.1 ± 1.8	0.09	2.38
aLDFA (°)	82.6 ± 2.0	81.8 ± 1.9	0.004	4.23
JLCA (°)	3.9 ± 2.4	-	-	
Posterior tibial slope (°)	6.2 ± 2.3	5.7 ± 2.1	0.09	1.71

TABLE 4: Radiographic alignment

Data are presented as means ± standard deviations. Values are denoted in degrees (°). The data were analyzed with a paired t-test. A p-value <0.05 was considered statistically significant. Negative values indicate valgus alignment.

TFA: Tibiofemoral angle, aMPTA: Anatomic medial proximal tibial angle, aLDFA: Anatomic lateral distal femoral angle, JLCA: Joint line convergence angle

Discussion

The main finding of this study was that cementless robotic-assisted restricted KA TKA demonstrated excellent early aseptic survivorship and favorable patient-reported outcomes at short-term follow-up. In addition, robotic assistance facilitated consistent execution of KA principles while achieving individualized alignment targets within predefined coronal and sagittal boundaries.

Interest in patient-specific alignment strategies for TKA has increased substantially in recent years [16,17]. Kinematic alignment attempts to better individualize component positioning and preserve more physiologic

knee balance while minimizing soft tissue releases [2,14,18]. In the present study, a restricted KA technique was utilized to balance individualized alignment restoration with implant durability considerations. Concurrently, robotic-assisted TKA has gained widespread adoption because of its ability to improve the precision and reproducibility of component positioning while providing detailed intraoperative assessment of alignment and soft tissue balance [19]. The present study demonstrates that cementless robotic-assisted KA TKA can be performed with favorable early clinical outcomes and implant survivorship.

One concern surrounding KA, particularly when combined with cementless fixation, is the potential for abnormal load distribution and early implant loosening. Nakamura et al. reported that KA increased contact stress on the tibial insert, medial tibial cortex, and bone resection surface in varus knees [20]. Similarly, Song et al. demonstrated increased peak contact stresses on the tibial insert at 90° and 120° of flexion with KA compared with MA [21]. In contrast, other investigations have reported more favorable biomechanical outcomes. Klasan et al. found that KA reduced contact pressures on the tibial polyethylene bearing surface by increasing contact area throughout the gait cycle [22]. Niki et al. demonstrated a reduction in knee adduction moment during gait with KA compared to MA [23], while Koh et al. reported improved restoration of native patellar kinematics and patellofemoral contact pressure during deep knee flexion [24]. Despite the use of individualized coronal and sagittal alignment targets, no cases of radiographic aseptic loosening or aseptic revision were identified in the present study. These findings are consistent with those of Flanagan et al., who reported no cases of aseptic loosening at a mean follow-up of 17.6 months after cementless manual calipered KA TKA [25]. Although longer-term follow-up remains necessary, the available evidence suggests that KA may be compatible with contemporary cementless fixation strategies when performed within restricted alignment boundaries.

The postoperative radiographic alignment distribution observed in the present study reflects the intended restricted KA philosophy rather than conventional MA targets. Mean postoperative aMPTA, aLDFA, and posterior tibial slope values demonstrated consistent restoration of individualized alignment while remaining within predefined boundaries. Notably, 80% of patients maintained their native coronal joint line orientation within 2° of baseline. Previous studies have shown that robotic-assisted TKA improves the accuracy and precision of component positioning compared with conventional instrumentation and may reduce alignment outliers [26]. Because intended component position varies substantially between patients undergoing KA TKA, reliable execution of patient-specific alignment targets is critical. The present findings suggest that robotic assistance may be particularly valuable in this setting by facilitating consistent implementation of individualized alignment plans.

The patient-reported outcomes observed in this series are encouraging and generally consistent with prior reports of KA TKA. Comparative studies and meta-analyses have demonstrated equivalent or improved functional outcomes and patient satisfaction following KA compared with MA, without increased complication and revision rates [18,27-30]. Although clinically meaningful improvement was achieved in only 33.3% and 50.9% of patients for PROMIS PF and PROMIS PI, respectively, these findings should be interpreted in the context of the incomplete PROMIS follow-up and potential for response bias. Despite these MCID achievement rates, significant improvements were observed across all PROMIS domains, and overall patient-reported outcomes remained favorable, with high patient satisfaction and low joint awareness at final follow-up.

This study has several limitations. First, the retrospective design introduces potential for selection bias. Next, all procedures were performed by a single fellowship-trained arthroplasty surgeon utilizing a consistent surgical philosophy and robotic workflow, which may limit generalizability. Next, follow-up was limited to early clinical outcomes, and longer-term evaluation will be necessary to determine the durability and implant survivorship of cementless robotic-assisted KA TKA. Next, incomplete PROMIS follow-up may have introduced response bias and affected estimates of clinically meaningful improvement. Next, preoperative FJS scores were not available for postoperative comparison. Lastly, the absence of a comparative control cohort precluded direct comparison with conventional MA or alternative alignment strategies.

Conclusions

Cementless robotic-assisted restricted KA TKA demonstrated excellent early aseptic survivorship and favorable patient-reported outcomes at short-term follow-up. A broad postoperative alignment distribution consistent with restricted KA principles was achieved while remaining within predefined coronal and sagittal alignment boundaries. These findings support the early compatibility of restricted KA with contemporary cementless fixation. Further comparative studies are warranted to evaluate the long-term durability and functional implications of this alignment strategy.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Alex M. Hollenberg, Andrew M. Schneider, Nicholas M. Brown

Acquisition, analysis, or interpretation of data: Alex M. Hollenberg, Andrew M. Schneider, Lane H. McCoy

Drafting of the manuscript: Alex M. Hollenberg, Andrew M. Schneider

Critical review of the manuscript for important intellectual content: Alex M. Hollenberg, Andrew M. Schneider, Lane H. McCoy, Nicholas M. Brown

Supervision: Andrew M. Schneider, Nicholas M. Brown

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. The Washington University in St. Louis Institutional Review Board issued approval 202408089. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** Andrew M Schneider declare(s) personal fees from Stryker. Research. Nicholas Brown declare(s) personal fees from Microport. Nicholas Brown declare(s) personal fees and royalties from Corin. Nicholas Brown declare(s) stock/stock options from MSKAI. Nicholas Brown declare(s) personal fees and royalties from Link. Nicholas Brown declare(s) personal fees and royalties from Zimmer Biomet. Andrew M Schneider declare(s) personal fees from Zimmer Biomet. Research. Nicholas Brown declare(s) non-financial support from Journal of Arthroplasty editorial board. Nicholas Brown declare(s) non-financial support from Arthroplasty Today associate editor. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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