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Two-Year Functional Outcomes of Kinematic Versus Mechanical Alignment in Primary Total Knee Arthroplasty: A Single-Surgeon Propensity-Matched Study in an Asian Population

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Abstract

Background

Optimal coronal alignment in total knee arthroplasty (TKA) remains controversial, with kinematic alignment (KA) emerging as a patient-specific alternative to conventional mechanical alignment (MA). This study compared two-year functional outcomes, patient-reported outcome measures (PROMs), and complication rates between KA-TKA and MA-TKA in a propensity score–matched cohort.

Methods

This retrospective single-surgeon study included 1,978 consecutive primary TKAs (KA: n = 921, 2018–2023; MA: n = 1,057, 2010–2014). After excluding revision cases and patients with incomplete follow-up, 1,451 primary TKAs were eligible. Following 1:1 propensity score matching for age, sex, BMI, and baseline PROMs, 536 matched pairs (n = 1,072) were analysed. Outcomes included range of motion, Knee Society Knee and Function Scores (KSKS, KSFS), Oxford Knee Score (OKS), SF-36, MCID attainment, satisfaction, complications, and revision rates at six months and two years.

Results

Both groups showed substantial postoperative improvement across all outcomes. At six months, KA achieved higher postoperative KSKS (86.7 vs 85.3, $p < 0.001$), greater flexion (113.1° vs 110.9°, $p = 0.010$), greater arc of motion (109.8° vs 107.5°, $p = 0.032$), and superior physical functioning, while MA showed greater improvement and higher MCID attainment in SF-36 role physical and bodily pain. Satisfaction at six months was higher with KA (95.6% vs 90.8%, $p = 0.003$). At two years, KA maintained superior KSKS (89.2 vs 86.3, $p < 0.001$), higher KSFS (77.6 vs 75.6, $p = 0.022$), improved range of motion, and better physical functioning. Satisfaction remained high and comparable (95.3% vs 95.7%, $p = 0.838$). Complication and revision rates were comparable, with equivalent two-year revision-free survival (98.0% vs 98.2%, $p = 0.788$).

Conclusion

KA-TKA provides comparable or superior early- to mid-term functional outcomes relative to MA-TKA, with similar safety and revision-free survival at two years. These findings support KA as an effective alignment strategy for primary TKA, although longer-term follow-up is required.

1. Introduction

Establishing optimal coronal alignment in total knee arthroplasty (TKA) remains a persistent challenge in knee reconstruction, contributing to patient dissatisfaction in approximately 20% of cases [1]. Alignment

philosophy is a major determinant of postoperative patient-reported outcome measures (PROMs). Historically, arthroplasty practice has been polarised between systematic, target-driven strategies and individualised, patient-specific approaches. Mechanical alignment (MA) seeks to restore a neutral coronal limb axis, typically defined as a hip–knee–ankle (HKA) angle of 180° [2]. In contrast, patient-specific paradigms represented by kinematic alignment (KA) aim to reproduce the patient's native limb and joint line geometry [3]. Intermediate and hybrid strategies have subsequently emerged to reconcile the theoretical advantages and limitations of MA and KA; these include adjusted mechanical alignment (aMA) [4], restricted kinematic alignment (rKA) [5], and functional alignment (FA) [6], Each philosophy entails distinct principles for bone resection and soft-tissue balancing, with important implications for component positioning, ligament tensioning, biomechanics, implant longevity, and clinical outcomes.

MA has long been regarded as the reference standard in total knee arthroplasty, supported by improved PROMs and substantial historical evidence of durable implant survivorship [7, 8]. The MA philosophy standardises bone resection and component positioning to achieve a neutral HKA axis, thereby simplifying surgical technique and facilitating reproducible implant fixation. However, MA inherently disregards considerable inter-individual variability in native coronal alignment and joint-line obliquity [9, 10]. By imposing a uniform limb axis, MA alters native ligament tensioning and joint kinematics, necessitating more frequent soft-tissue releases to achieve balance and potentially disrupting load distribution across the prosthetic surfaces and periprosthetic bone [11–13]. Such alterations have been implicated in non-physiological contact stresses, asymmetric polyethylene wear, and aberrant mechanical loading that may compromise long-term implant performance in certain patients.

KA adopts a contrasting, patient-specific strategy in which components are positioned to restore pre-arthritic joint lines and native limb alignment, aiming to re-establish native ligament tension and knee kinematics. KA typically reduces the extent of ligament releases required intraoperatively and preserves collateral ligament length–tension relationships, which may facilitate more physiologic patellofemoral tracking and tibiofemoral motion [14, 15]. Early clinical and biomechanical reports suggest that KA is associated with faster functional recovery, greater early range of motion, and improved patient-perceived naturalness of the reconstructed knee [14]. Despite increasing evidence comparing KA and MA in TKA, most studies have been conducted in predominantly Western populations, limiting generalisability to Asian cohorts. This distinction may be clinically relevant, as Asian populations have been reported to exhibit differences in constitutional lower limb alignment, including a higher prevalence of constitutional varus, as well as population-specific knee morphology and femoral bowing patterns that may influence implant positioning and soft-tissue balance [16, 17]. In addition, cultural and lifestyle factors such as frequent squatting, kneeling, and floor-based activities place greater functional demands on postoperative knee flexion. These anatomical and functional differences may affect the relative performance of alignment strategies and warrant dedicated evaluation in Asian populations.

This large-scale, single-surgeon study therefore aimed to compare functional outcomes, patient-reported outcome measures, and safety outcomes between mechanical and kinematic alignment in primary TKA

within an Asian population, with particular focus on early- to mid-term recovery, range of motion, and revision rates.

2. Materials and Methods

2.1 Study Design and Patient Selection

This retrospective propensity score-matched cohort study compared outcomes following conventional primary total knee arthroplasty (TKA) performed using mechanical alignment (MA) and kinematic alignment (KA) by a single fellowship-trained surgeon. MA TKAs were performed between 2010 and 2014, whereas KA TKAs were performed between 2018 and 2023. Ethical approval was obtained from the Centralised Institutional Review Board and Ethics Committee prior to study initiation (CIRB Ref: 2024/4046), and the study was conducted in accordance with the Declaration of Helsinki. Patient data were extracted from the institutional TKA registry and anonymised prior to analysis.

A total of 1,978 patients who underwent conventional TKA were initially identified. Patients who underwent revision TKA were excluded (n = 76), yielding an eligible cohort of 1,902 patients. Patients with incomplete follow-up data at 6 months or 2 years were subsequently excluded (n = 451). To minimise selection bias and account for baseline differences between alignment strategies, propensity score matching was performed using 1:1 nearest-neighbour matching based on age, sex, demographic variables, and preoperative functional scores. Following matching, 536 patients in the KA group were matched to 536 patients in the MA group, resulting in a final study cohort of 1,072 patients (all standardised mean differences < 0.1 after matching). This sample size met the requirements established by a pre-study power analysis. A priori power analysis was conducted based on the MCID of the OKS and standard deviation reported by Clement et al., yielding an effect size of 0.82 [18]. To achieve 90% power with an alpha level of 0.05, a minimum of 27 patients per group was required to detect a significant difference between independent means. A separate power analysis in a South-East Asian population by Liow et al. indicated that 29 knees per group were sufficient to detect clinically relevant differences between TKA cohorts [19].

Demographic variables recorded included age, sex, race, height, and body mass index (BMI). Patient-reported and clinician-assessed outcome measures collected preoperatively and postoperatively included the Knee Society Knee Score (KSKS), Knee Society Function Score (KSFS), Oxford Knee Score (OKS), and the Short Form-36 (SF-36) [18, 20, 21].

2.2 Surgical Technique

All patients underwent the standard medial parapatellar approach and received a cruciate-retaining, fixed bearing cemented total knee system (P.F.C.® Total Knee System, DePuy Synthes, Massachusetts, United States).

2.2.1 Mechanical Alignment Technique

Femoral alignment was established using an intramedullary rod inserted approximately 7–10 mm anterior to the posterior cruciate ligament origin, with the valgus correction angle set between 5° and 7° according to preoperative long-leg radiographic planning. Distal femoral resection involved removal of at least 9 mm of bone from the more prominent femoral condyle. Tibial preparation was performed using an extramedullary alignment jig centred over the medial third of the tibial tubercle and aligned distally with the transmalleolar axis. The tibial posterior slope was fixed at 5°, and the resection depth was referenced from the tibial plateau using a stylus. Flexion and extension gaps were balanced with spacer blocks to achieve a rectangular gap configuration. Femoral component rotation was subsequently set at 3° of external rotation relative to the posterior condylar axis, followed by chamfer cuts and patellar resurfacing to restore native patellar thickness. After satisfactory trialling, the definitive implants were cemented in place and standard layered wound closure was performed.

2.2.2 Kinematic Alignment Technique

In the unrestricted kinematic alignment total knee arthroplasty (uKA-TKA) group, patients underwent routine calipered KA-TKA as described by Stephen M. Howell [3]. A standard medial parapatellar approach was similarly used in all cases. Following exposure of the joint, residual intact cartilage on the distal femur was removed down to subchondral bone. Distal femoral resection was performed using the femoral cutting guide while accounting for approximately 2 mm of cartilage wear and 1 mm sawblade thickness to reproduce the 9 mm implant thickness, resulting in a planned 6 mm resection from both the medial and lateral femoral condyles, confirmed using calipers. The posterior referencing guide was positioned at 0° rotation relative to the posterior condyles. In cases with tibial bone loss, a line parallel to the native posterior condylar axis was marked on the tibia to guide the varus–valgus orientation of the tibial cut. Proximal tibial resection was then performed using a conventional extramedullary guide and verified with caliper measurements. The posterior tibial slope was adjusted to reproduce the native anatomy, with approximately 8 mm of resection from the lateral tibial plateau. The objective was to achieve equivalent medial and lateral tibial resections in the anteroposterior plane, with intraoperative adjustments made where required. All patellae were resurfaced using an onlay prosthesis. Final femoral sizing was then completed, followed by use of the appropriate 4-in-1 cutting block to complete the femoral resections. Following satisfactory trial implantation, the definitive components were cemented and standard layered closure was performed.

Postoperative care followed a standardised institutional protocol for all patients. This protocol included same-day mobilisation with physiotherapy initiated on postoperative day 0 and a multimodal, opioid-sparing analgesic regimen. Analgesia consisted of paracetamol and nonsteroidal anti-inflammatory drugs (NSAIDs) when not contraindicated. The protocol was applied uniformly across all study participants.

2.3 Data Collection

Demographic data such as age, sex and body mass index were recorded. Patients were assessed by independent trained assessors at the institution’s Orthopaedic Diagnostic Centre (ODC). Data measured

included active range of motion (flexion and extension) and PROMs such as the Knee Society Knee (KSKS) and Function Scores (KSFS), the Oxford Knee Score (OKS), and the Short Form-36 (SF-36) at 6 months and 2 years postoperatively. The proportion of patients achieving the minimal clinically important difference (MCID) at six months was computed for both the MA and KA cohorts. These MCID thresholds were derived from established values in the existing literature [21–23].

2.4 Statistical Analysis

Continuous variables were assessed for normality using the Shapiro–Wilk test. Normally distributed data were presented as mean ± standard deviation (SD), while categorical variables were expressed as frequencies and percentages. Comparisons between groups were performed using the independent-samples t-test for normally distributed continuous variables and the Mann–Whitney U test for non-parametric variables. Categorical variables were compared using the chi-square test or Fisher's exact test where appropriate. Statistical significance was defined as a two-tailed p value < 0.05. To mitigate treatment selection bias, propensity score matching was employed. Cohen's d is reported for baseline continuous variables as a standardised effect size to support comparability between groups independent of sample size; $|d|<0.2$ is conventionally considered a negligible difference [24]. Propensity scores were estimated via logistic regression incorporating baseline demographics (age, sex, body mass index) and all available preoperative patient-reported outcome measures. Optimal 1:1 matching using nearest neighbour matching without replacement was used to form balanced mechanical and kinematic alignment cohorts; 536 patients per group were retained for comparative analyses. All statistical analyses were performed using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA). Revision-free survival to 2 years was estimated using the Kaplan-Meier method and groups compared using the log-rank test.

Table 1
Incclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Patients undergoing Primary TKA	Patients undergoing revision TKA
Patients undergoing TKA for primary end-stage knee OA	Patients undergoing TKA for indications other than primary knee OA (e.g., inflammatory arthritis)
Use of conventional instrumentation systems	Use of robotic systems.
Documentation of early outcome data (e.g., Surgical Duration, post-operative pain scores, LOS, and ambulation distance) and pre-operative and 6 months functional outcomes (e.g., KSS, SF-36)	Missing early outcome data, pre-operative, 6 months and 2 years functional data (e.g., from lost-to-follow-up)

3. Results

3.1 Demographics

A total of 1451 primary TKAs were included. After 1:1 nearest neighbour propensity matching based on age, sex, BMI and baseline PROMs, 536 well-balanced pairs were obtained. Before matching, differences were observed in age and several baseline SF-36 domains. Propensity score matching yielded two well-balanced cohorts of 536 patients each, with all matched variables demonstrating negligible effect sizes (Cohen's d < 0.10) and no statistically significant between-group differences (p > 0.05), confirming adequate covariate balance prior to outcome analysis. The matched cohorts had comparable baseline demographics, PROMs and ROM (Table 2).

Table 2
Baseline demographics

Age (years)	**KA**	**MA**	**p-value**	**Cohen's d**
	68.6 ± 7.3	**68.8 ± 7.0**	**0.453**	**-0.03**
BMI (kg/m²)	27.3 ± 4.6	27.1 ± 4.1	0.906	0.02
Female sex (%)	76.1%	77.1%	0.773	—
Flexion (°)	116.6 ± 17.7	117.4 ± 17.5	0.328	-0.05
Extension (°)	6.8 ± 7.0	7.5 ± 7.6	0.204	-0.09
Range of motion (°)	109.8 ± 21.2	110.0 ± 20.2	0.827	-0.01
Preop Knee Society Knee Score (KSKS)	37.2 ± 17.3	36.7 ± 17.1	0.647	0.03
Preop Knee Society Function Score (KSFS)	53.4 ± 18.2	52.7 ± 17.6	0.641	0.04
Preop Oxford Knee Score (OKS)	35.0 ± 7.9	35.3 ± 7.8	0.544	-0.05
Preop SF-36 Physical Function	41.3 ± 25.2	39.3 ± 22.1	0.289	0.08
Preop SF-36 Role Physical	18.5 ± 32.5	16.2 ± 30.2	0.242	0.07
Preop SF-36 Bodily Pain	33.4 ± 17.7	32.5 ± 16.2	0.784	0.06
Preop SF-36 General Health	68.7 ± 20.7	68.0 ± 20.3	0.576	0.03
Preop SF-36 Vitality	71.1 ± 21.9	70.6 ± 21.1	0.632	0.02
Preop SF-36 Social Function	55.9 ± 35.7	52.7 ± 35.3	0.103	0.09
Preop SF-36 Role Emotional	91.8 ± 26.6	91.3 ± 27.3	0.682	0.02
Preop SF-36 Mental Health	80.7 ± 17.3	80.1 ± 17.3	0.535	0.04
Preop SF-36 Physical Component Summary (PCS)	32.9 ± 9.2	32.1 ± 8.3	0.268	0.09
Preop SF-36 Mental Component Summary (MCS)	52.4 ± 11.4	51.9 ± 11.1	0.325	0.04

3.2 6-month postoperative outcomes

At 6 months, both KA and MA groups demonstrated substantial postoperative improvements across all PROMs. KA achieved significantly higher postoperative Knee Society Knee Scores (KSKS) (86.7 vs 85.3, $p < 0.001$), greater end-range flexion (113.1° vs 110.9°, $p = 0.010$), and greater arc of motion (109.8° vs 107.5°, $p = 0.032$), while extension was comparable between groups. Postoperative Knee Society Function Scores (KSFS), Oxford Knee Scores (OKS), and their respective change-from-baseline scores were comparable between groups, with no significant differences in MCID attainment.

For SF-36 domains, KA demonstrated significantly higher physical functioning scores at 6 months (70.3 vs 67.6, $p < 0.001$). In contrast, MA showed greater improvement in role physical (54.1 vs 48.3, $p = 0.040$) and bodily pain (36.8 vs 33.2, $p = 0.023$), with higher MCID attainment for both domains (role physical: 75.7% vs 69.1%, $p = 0.018$; bodily pain: 78.7% vs 72.9%, $p = 0.031$). All other SF-36 domains, including physical component summary (PCS) and mental component summary (MCS), were comparable between cohorts. Patient satisfaction was high in both groups but significantly greater in the KA group (95.6% vs 90.8%, $p = 0.003$) (Table 3).

Table 3
6-month PROMs and ROM outcomes

	KA	MA	p-value
Knee Society Knee Score (KSKS)			
Score at 6 months	86.7 ± 12.9	85.3 ± 11.1	< 0.001
Change from baseline	49.6 ± 20.9	48.6 ± 19.7	0.244
MCID attained (≥ 6.4), %	96.7%	97.1%	0.814
Knee Society Function Score (KSFS)			
Score at 6 months	72.4 ± 18.4	71.4 ± 17.0	0.229
Change from baseline	19.0 ± 20.6	18.6 ± 19.2	0.876
MCID attained (≥ 5.9), %	70.3%	74.6%	0.137
Oxford Knee Score (OKS)			
Score at 6 months	19.5 ± 5.5	19.0 ± 4.5	0.649
Change from baseline	15.4 ± 8.4	16.3 ± 8.0	0.109
MCID attained (≥ 5.0), %	90.8%	93.5%	0.135
SF-36 Physical Function			
Score at 6 months	70.3 ± 23.5	67.6 ± 20.0	< 0.001
Change from baseline	29.1 ± 27.9	28.3 ± 23.6	0.611
MCID attained (≥ 11.6), %	72.5%	75.0%	0.392
SF-36 Role Physical			
Score at 6 months	66.9 ± 39.8	70.3 ± 37.8	0.257
Change from baseline	48.3 ± 46.6	54.1 ± 44.5	0.040
MCID attained (≥ 11.7), %	69.1%	75.7%	0.018
SF-36 Bodily Pain			
Score at 6 months	66.6 ± 26.4	69.3 ± 23.7	0.114
Change from baseline	33.2 ± 28.6	36.8 ± 26.2	0.023
MCID attained (≥ 16.9), %	72.9%	78.7%	0.031
SF-36 General Health			
Score at 6 months	73.2 ± 20.0	74.0 ± 19.0	0.752

	KA	MA	p-value
Knee Society Knee Score (KSKS)			
Change from baseline	4.5 ± 20.7	6.0 ± 20.5	0.202
MCID attained (≥ 0.9), %	53.9%	55.4%	0.655
SF-36 Vitality			
Score at 6 months	75.8 ± 18.8	76.6 ± 19.4	0.292
Change from baseline	4.8 ± 22.2	6.0 ± 22.7	0.110
MCID attained (≥ 3.9), %	49.0%	50.9%	0.561
SF-36 Social Function			
Score at 6 months	87.6 ± 23.9	87.0 ± 26.2	0.608
Change from baseline	31.9 ± 39.9	34.3 ± 38.5	0.297
MCID attained (≥ 11.7), %	62.1%	66.0%	0.206
SF-36 Role Emotional			
Score at 6 months	96.7 ± 16.1	96.8 ± 16.7	0.374
Change from baseline	5.0 ± 29.2	5.5 ± 29.7	0.370
MCID attained (≥ 7.8), %	8.7%	9.3%	0.785
SF-36 Mental Health			
Score at 6 months	86.4 ± 13.1	86.4 ± 14.0	0.383
Change from baseline	5.7 ± 17.5	6.3 ± 18.1	0.224
MCID attained (≥ 0.3), %	49.2%	54.5%	0.093
SF-36 Physical Component Summary (PCS)			
Score at 6 months	47.0 ± 9.6	47.2 ± 9.2	0.588
Change from baseline	14.2 ± 11.9	15.1 ± 10.7	0.308
MCID attained (≥ 10.0), %	64.2%	69.4%	0.083
SF-36 Mental Component Summary (MCS)			
Score at 6 months	56.5 ± 9.5	56.8 ± 9.6	0.543
Change from baseline	4.1 ± 11.1	4.9 ± 11.0	0.083
MCID attained (≥ 10.0), %	26.4%	28.2%	0.553
Range of Motion			

	KA	MA	p-value
Knee Society Knee Score (KSKS)			
Flexion at 6 months	113.1 ± 13.4	110.9 ± 13.7	0.010
Extension at 6 months	3.3 ± 4.4	3.3 ± 4.7	0.666
Range of motion at 6 months	109.8 ± 15.1	107.5 ± 15.3	0.032
Patient Satisfaction			
% satisfied	95.6%	90.8%	0.003

3.3 2 year postoperative outcomes

At 24 months, excellent outcomes were sustained in both groups. KA demonstrated significantly higher postoperative Knee Society Knee Scores (KSKS) (89.2 vs 86.3, $p < 0.001$) and Knee Society Function Scores (KSFS) (77.6 vs 75.6, $p = 0.022$), although change-from-baseline scores and MCID attainment for both measures were comparable. Oxford Knee Scores (OKS), change scores, and MCID attainment were also similar between groups.

KA maintained superior range of motion at 2 years, with greater end-range flexion (116.6° vs 114.0°, $p < 0.001$) and greater arc of motion (115.7° vs 113.1°, $p = 0.001$), while extension remained comparable. Among SF-36 domains, KA demonstrated significantly higher physical functioning scores (75.7 vs 72.0, $p < 0.001$), whereas all other SF-36 domains, including bodily pain, PCS, and MCS, showed no significant between-group differences. Patient satisfaction remained high and comparable between groups (95.3% vs 95.7%, $p = 0.838$) (Table 4).

Table 4
24-month PROMs and ROM outcomes

	KA	MA	p-value
Knee Society Knee Score (KSKS)			
Score at 2 years	89.2 ± 10.3	86.3 ± 11.7	< 0.001
Change from baseline	51.8 ± 19.2	49.5 ± 20.8	0.089
MCID attained (≥ 6.4), %	98.1%	96.1%	0.093
Knee Society Function Score (KSFS)			
Score at 2 years	77.6 ± 18.7	75.6 ± 17.8	0.022
Change from baseline	24.3 ± 21.4	22.9 ± 20.1	0.164
MCID attained (≥ 5.9), %	81.1%	80.4%	0.828
Oxford Knee Score (OKS)			
Score at 2 years	17.7 ± 4.5	18.1 ± 4.4	0.053
Change from baseline	17.2 ± 7.9	17.3 ± 7.9	0.961
MCID attained (≥ 5.0), %	95.9%	95.5%	0.890
SF-36 Physical Function			
Score at 2 years	75.7 ± 20.3	72.0 ± 19.3	< 0.001
Change from baseline	34.5 ± 26.1	32.7 ± 23.2	0.431
MCID attained (≥ 11.6), %	80.7%	81.5%	0.792
SF-36 Role Physical			
Score at 2 years	75.6 ± 37.3	77.4 ± 35.1	0.921
Change from baseline	57.1 ± 46.8	61.1 ± 45.1	0.200
MCID attained (≥ 11.7), %	73.5%	78.5%	0.068
SF-36 Bodily Pain			
Score at 2 years	73.3 ± 24.6	72.6 ± 25.3	0.747
Change from baseline	39.8 ± 27.7	40.1 ± 28.2	0.682
MCID attained (≥ 16.9), %	81.1%	79.6%	0.611
SF-36 General Health			
Score at 2 years	73.7 ± 20.5	73.0 ± 19.6	0.362

	KA	MA	p-value
Knee Society Knee Score (KSKS)			
Change from baseline	5.1 ± 23.0	4.9 ± 21.5	0.957
MCID attained (≥ 0.9), %	57.2%	54.4%	0.384
SF-36 Vitality			
Score at 2 years	77.0 ± 18.1	77.8 ± 18.6	0.297
Change from baseline	6.0 ± 22.5	7.2 ± 22.5	0.371
MCID attained (≥ 3.9), %	52.3%	50.5%	0.580
SF-36 Social Function			
Score at 2 years	92.7 ± 19.1	91.3 ± 22.2	0.915
Change from baseline	37.0 ± 37.9	38.6 ± 39.1	0.317
MCID attained (≥ 11.7), %	64.9%	67.9%	0.342
SF-36 Role Emotional			
Score at 2 years	98.1 ± 12.9	96.0 ± 18.9	0.072
Change from baseline	6.3 ± 28.5	4.7 ± 30.0	0.569
MCID attained (≥ 7.8), %	8.6%	8.6%	1.000
SF-36 Mental Health			
Score at 2 years	86.6 ± 13.7	86.8 ± 13.4	0.995
Change from baseline	5.9 ± 18.0	6.7 ± 18.4	0.342
MCID attained (≥ 0.3), %	52.9%	56.8%	0.221
SF-36 Physical Component Summary (PCS)			
Score at 2 years	49.7 ± 8.0	49.1 ± 8.7	0.110
Change from baseline	16.9 ± 11.4	17.0 ± 11.3	0.696
MCID attained (≥ 10.0), %	72.8%	74.4%	0.601
SF-36 Mental Component Summary (MCS)			
Score at 2 years	57.0 ± 9.7	57.1 ± 9.2	0.767
Change from baseline	4.7 ± 11.7	5.1 ± 10.8	0.247
MCID attained (≥ 10.0), %	29.1%	31.2%	0.488
Range of Motion			

	KA	MA	p-value
Knee Society Knee Score (KSKS)			
Flexion at 2 years	116.6 ± 13.5	114.0 ± 12.9	< 0.001
Extension at 2 years	0.8 ± 4.3	1.0 ± 4.2	0.919
Range of motion at 2 years	115.7 ± 14.9	113.1 ± 14.4	0.001
Patient Satisfaction			
% satisfied	95.3%	95.7%	0.838

3.4 Complication Rates

Complication rates were broadly comparable between cohorts, with low event rates in both groups. In the KA group, five patients underwent manipulation under anaesthesia (MUA) for postoperative knee stiffness, and one patient required arthrotomy and insert exchange for recurvatum deformity. In the MA group, four patients underwent MUA for knee stiffness, and two patients sustained periprosthetic fractures managed with fixation; no MA patient required revision surgery within the study period. Stiffness rates were low and similar between groups, consistent with reported MUA rates following primary TKA in the literature. Two-year revision-free survival was 99.8% in the KA group versus 100.0% in the MA group (log-rank p = 0.317), indicating no significant difference in revision risk between alignment techniques (Fig. 1).

4. Discussion

According to a systematic review by Rivière et al., KA is associated with accelerated early recovery and superior short-term functional outcomes compared with MA [25]. These benefits are hypothesised to result from the restoration of native joint-line geometry and ligament tension, reduced need for soft-tissue releases, and more physiologic kinematics that facilitate pain reduction and improved gait. However, the magnitude and durability of the functional advantage vary across studies and patient subgroups, and concerns remain about load distribution and implant longevity in patients with severe preoperative deformity. Therefore, careful patient selection and long-term comparative data are required to define the subpopulations that derive the greatest net benefit from KA.

Our findings are broadly consistent with a meta-analysis demonstrating superior short-term outcomes with KA-TKA compared with MA-TKA, including improved Knee Society scores and greater postoperative knee flexion [26]. Similarly, Yeo et al. reported comparable clinical and radiographic outcomes between robotic MA and KA strategies at a mean follow-up of eight years [27]. Our findings are broadly consistent with this literature. In our cohort, KA demonstrated superior early postoperative outcomes, with higher Knee Society Knee Scores, greater postoperative flexion and range of motion, improved physical functioning, and higher patient satisfaction at 6 months. These functional advantages persisted at 24 months, with KA maintaining superior Knee Society Knee and Function Scores together with sustained

improvements in range of motion and physical functioning. However, the magnitude of these differences was modest. KA was associated with higher patient satisfaction at 6 months, although this advantage was not sustained at two years, and most MCID attainment rates remained comparable between groups. This suggests that while KA may confer measurable biomechanical or functional advantages, the clinical impact at a patient-perceived level may be limited in the short to mid-term.

Use of patient-specific instrumentation to perform kinematically aligned TKA without limiting preoperative deformity did not compromise implant survival, annual revision rates, or functional outcomes over a 10-year period [28]. Similarly, at a mean follow-up of 6.3 years, residual varus of the tibial component, knee, or limb after KA-TKA was not associated with reduced implant survival or poorer function, supporting KA as a valid alternative to mechanical alignment for primary TKA [29].

Complication rates were were broadly comparable between cohorts, with low event rates in both groups. In the KA-TKA group, one patient developed PJI requiring two-stage revision with implant removal and cement spacer insertion, and one patient required arthrotomy and insert exchange for recurvatum deformity. Nine KA patients underwent MUA for post-operative knee stiffness. In the MA-TKA group, four patients were diagnosed with PJI, managed variably with arthrotomy and washout, polyethylene liner exchange, or implant removal and prosthesis exchange; three patients sustained periprosthetic fractures requiring operative or conservative management; and six patients underwent MUA for knee stiffness. Periprosthetic fractures occurred only in the MA group, which may be attributable to the older operative period rather than alignment strategy itself. MUA rates for post-operative stiffness were low and similar between groups (KA: 1.3%, MA: 1.5%), in keeping with reported rates of 4% following primary TKA in the literature [30]. Overall, two-year revision-free survival was equivalent between groups (99.8% vs 100%, long-rank p = 0.317), confirming that KA does not carry a greater revision risk than MA in the short to mid term..

Key strengths of this study include the application of propensity score matching to minimise confounding between groups, and the direct comparison of two alignment philosophies performed exclusively by a single experienced surgeon within a single institution, ensuring standardised perioperative and rehabilitation protocols throughout. The systematic collection of multiple validated patient-reported and functional outcome measures by trained physiotherapists further reduces the risk of assessor bias.

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Several limitations warrant acknowledgement. The retrospective design and nonconcurrent nature of the cohorts — with MA-TKA cases recruited between 2010 and 2014 and KA-TKA cases between 2018 and 2023 — introduces the possibility of temporal confounding. Advances in perioperative care, evolving surgical technique, and other secular trends over this interval may have differentially influenced

outcomes in ways that propensity matching cannot fully account for. Also, while the two-year follow-up period permits assessment of early to mid-term functional outcomes, it is insufficient to draw conclusions regarding long-term implant survivorship in the KA-TKA cohort, and extended follow-up will be necessary to address this question.

5. Conclusions

This large-scale, propensity-score–matched, single-surgeon study demonstrates that kinematic alignment TKA achieves comparable and, in several clinically relevant domains, superior functional outcomes compared with mechanical alignment TKA at both six months and two years. KA conferred modest but consistent advantages in postoperative range of motion, knee-specific functional outcomes, and physical functioning, together with higher patient satisfaction at six months, although satisfaction was comparable between groups by two years. Complication and revision rates were low in both groups, with Kaplan–Meier analysis confirming equivalent two-year revision-free survival. These findings support KA as a safe and effective alternative to MA for primary TKA in an appropriately selected patient population. Longer-term follow-up will be necessary to determine whether these functional advantages are sustained and to establish long-term implant survivorship under kinematic alignment principles.

Declarations

Consent for Publication

Not applicable.

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Author Contribution

B.X.B.N was responsible for manuscript writing and data analysis. V.V.P was responsible for manuscript editing and data procurement. S.J.Y, H.N.P and K.J.D.T was responsible for manuscript editing. M.H.L.L was responsible for supervision, conceptualisation and manuscript editing.

Data Availability

The datasets that support the findings of this study were derived from the institutional total knee arthroplasty registry. Restrictions apply to the availability of these data due to patient confidentiality and institutional data governance policies; therefore, the data are not publicly available. Data may be made

available from the corresponding author upon reasonable request and with appropriate institutional approval.

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Figures

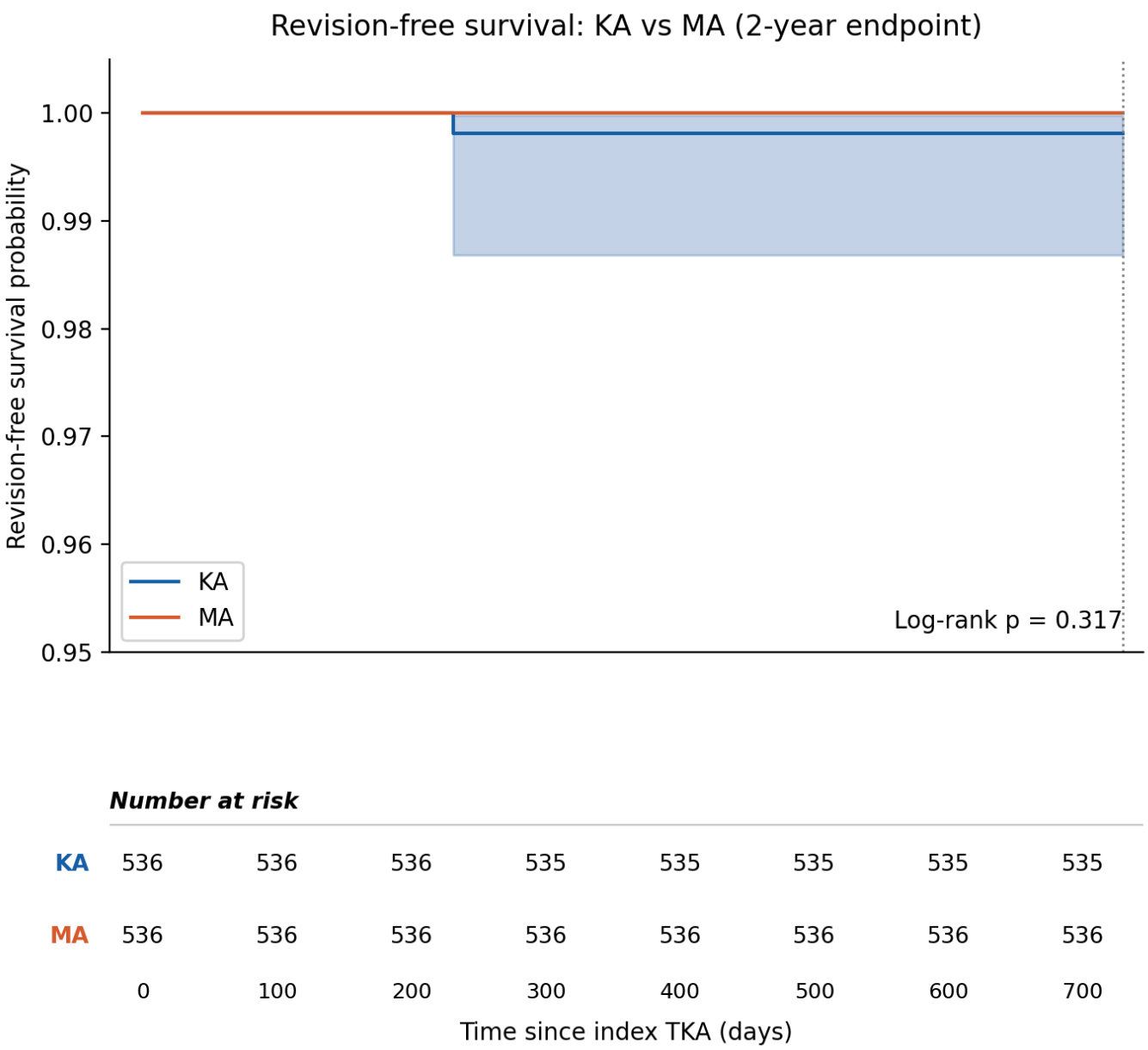


Figure 1

Revision-free survival (Kaplan-Meier, 2-year endpoint)