

Rehabilitation Guidelines for Kinematic Alignment in Primary Total Knee Arthroplasty: A Prospective Cohort Study

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ABSTRACT

Background: Kinematic alignment (KA) in total knee arthroplasty (TKA) is a surgical philosophy that aims to restore the patient's native, pre-arthritic knee anatomy and kinematics. This approach differs significantly from traditional mechanical alignment (MA), particularly in its preservation of the soft-tissue envelope without the need for ligamentous releases. While surgical outcomes have been extensively studied, there is a lack of specific, evidence-based rehabilitation guidelines tailored to the unique biomechanical principles of KA TKA.

Aim and Objective: The primary objective of this study was to develop and prospectively evaluate a specialized rehabilitation protocol for patients undergoing primary TKA with kinematic alignment. We aimed to assess the safety, efficacy, and functional outcomes associated with this protocol.

Methods: We conducted a prospective cohort study involving 60 patients who underwent primary KA TKA for osteoarthritis. A standardized, four-phase rehabilitation protocol was implemented, emphasizing immediate weight-bearing, early range of motion, and targeted patellofemoral stabilization exercises. Patient-reported outcome measures (PROMs), including the Knee Osteoarthritis Outcome Score (KOOS), Forgotten Joint Score (FJS), and Knee Society Score (KSS), were collected preoperatively and at 6 weeks, 3 months and 6 months postoperatively. Longitudinal data were analysed using repeated measures ANOVA.

Results: All 60 enrolled patients completed the 6-month follow-up. Significant improvements were observed across all PROMs from the preoperative baseline to the 6-month mark ($p < 0.001$). The mean FJS improved from 35.2 (SD 25.1) at 6 weeks to 72.5 (SD 18.8) at 6 months ($p < 0.001$). Mean knee flexion improved from 108° (SD 12.5°) preoperatively to 125° (SD 8.5°) at 6 months. Functional milestones were achieved rapidly, with 92% of patients walking without an assistive device by 6 weeks. No implant failures, revisions for loosening, or deep infections occurred within the study period.

Conclusion: This study presents a structured rehabilitation protocol specifically designed for the kinematic alignment TKA population. The protocol was found to be safe and effective, leading to excellent early functional recovery and high patient satisfaction. These guidelines, which leverage the biomechanical advantages of the KA technique, can help standardize postoperative care and optimize outcomes for this growing patient cohort.

Keywords: Kinematic Alignment, Total Knee Arthroplasty, Rehabilitation, Physical Therapy, Patient-Reported Outcome Measures, Functional Recovery

1. INTRODUCTION

Total knee arthroplasty (TKA) is one of the most successful surgical interventions performed worldwide, providing significant pain relief and functional improvement for patients with end-stage osteoarthritis¹. Despite high success rates, up to 20% of patients remain dissatisfied with the outcome, citing residual pain, stiffness, and a feeling that the prosthetic knee is unnatural. For decades, the gold standard for TKA has been mechanical alignment (MA), a technique that aims to create

a neutral hip-knee-ankle axis by making bone resections perpendicular to the mechanical axes of the femur and tibia². While this systematic approach was intended to ensure implant longevity by creating balanced load distribution, it often fails to replicate the patient's unique constitutional anatomy, necessitating soft-tissue releases to balance the flexion and extension gaps⁴. This alteration of the native soft-tissue envelope and kinematics may contribute to patient dissatisfaction³.

In response to these limitations, kinematic alignment (KA) has emerged as an alternative and increasingly popular surgical philosophy⁵. The fundamental goal of KA is to resurface the knee by co-aligning the implant components with the patient's three native kinematic axes of rotation. This technique restores the patient's pre-arthritis joint line obliquity and constitutional limb alignment, thereby preserving the physiological laxity of the ligaments without requiring soft-tissue releases. By restoring more normal knee biomechanics, KA has been associated with improved functional scores, a more natural-feeling knee, and faster patient recovery in several studies⁶.

Despite the growing body of literature on the surgical technique and clinical outcomes of KA TKA, a significant gap exists regarding postoperative management⁸. Rehabilitation protocols have historically been developed for patients undergoing MA TKA, which often involve precautions and timelines dictated by the extensive soft-tissue dissection and releases performed. Given that KA is inherently a more anatomic, soft-tissue-preserving procedure, it is logical to hypothesize that these patients may benefit from a distinct, possibly accelerated, rehabilitation pathway⁹. However, to date, no standardized, evidence-based guidelines for the rehabilitation of KA TKA patients have been published. The lack of a specific protocol may lead to suboptimal recovery or, conversely, overly cautious rehabilitation that fails to capitalize on the biomechanical advantages of the procedure⁷.

Therefore, the purpose of this study was to develop a structured, four-phase rehabilitation protocol tailored to the principles of KA TKA and to prospectively evaluate its safety and efficacy in a multicentre cohort⁹. We hypothesized that this

specialized protocol would lead to excellent functional outcomes, rapid achievement of recovery milestones, and high rates of patient satisfaction.

2. METHODS

Study Design and Population A prospective, multicentre trial was designed and conducted across three specialized orthopaedic centres. A total of 60 patients undergoing primary, unilateral KA TKA for a diagnosis of osteoarthritis were enrolled. The study was conducted in accordance with the Declaration of Helsinki and received approval from the institutional review board at each participating centre. All patients provided written informed consent prior to participation.

Surgical Technique All TKAs were performed by one of five fellowship-trained arthroplasty surgeons experienced in the caliper KA technique. A standard medial parapatellar approach was used. The femoral component was positioned to restore the native distal and posterior joint lines, and the tibial component was aligned to restore the native proximal joint line varus/valgus and slope, with resections verified using a precision calliper. A cruciate-retaining, medial-pivot implant design was used in all cases. Soft-tissue releases were not performed as part of the balancing algorithm.

Rehabilitation Protocol (The Intervention) A standardized, four-phase rehabilitation protocol was developed based on the biomechanical principles of KA TKA. The protocol was administered by licensed physical therapists at each centre.

Phase I: Acute Postoperative (In-Hospital, Days 0–4)

Goals: Control pain and oedema, achieve 0–90° active ROM, initiate quadriceps activation, and ambulate with an assistive device.

Intervention: Immediate weight-bearing as tolerated (WBAT) with crutches or a walker. Ankle pumps, quad sets, gluteal sets, and active heel slides were initiated on the day of surgery. Gait training, bed mobility, and transfer training were performed. Cryotherapy was used consistently.

Phase II: Early Outpatient Recovery (Weeks 1–6)

Goals: Wean off assistive device, achieve full active extension and at least 115° of flexion, and improve strength and endurance.

Intervention: Continued focus on ROM with stationary cycling, stretching, and patellar mobilization. Progressive strengthening exercises were introduced, including straight leg raises, mini-squats, and step-ups. Specific emphasis was placed on vastus medialis obliquus (VMO) strengthening and neuromuscular control for patellar tracking, given the reports of patellofemoral complications in some KA cohorts.

Phase III: Strengthening and Proprioception (Weeks 7–12)

Goals: Normalize gait without an assistive device, improve proprioception and balance, and build functional strength.

Intervention: More advanced, closed-chain strengthening exercises (e.g., leg press, single-leg balance). Introduction of proprioceptive training using balance boards and uneven surfaces. Functional activity simulation, such as stair climbing and

descending.

Phase IV: Return to Advanced Activity (Weeks 13+)

Goals: Return to unrestricted daily activities and recreational sports.

Intervention: Activity-specific training, low-impact aerobics, and a gradual return to activities such as golf, hiking, and cycling. Patient education on long-term joint health and activity modification.

Outcome Measures A comprehensive set of PROMs was collected preoperatively and at 6 weeks, 3 months and 6-month follow-up visits. These included:

Knee Osteoarthritis Outcome Score (KOOS)

Knee Society Score (KSS - Knee and Function Scores)

Forgotten Joint Score (FJS-12)

Pain Visual Analogue Scale (VAS) for rest and activity

Objective clinical measures included goniometric assessment of active knee flexion and extension ROM. Achievement of functional milestones (e.g., ambulation without an assistive device, reciprocal stair ascent/descent) was recorded at each follow-up. All adverse events, including re-admissions, manipulations under anaesthesia, and surgical complications, were documented.

Statistical Analysis Descriptive statistics, including means, standard deviations (SD), and frequencies, were used to summarize patient demographics and clinical outcomes. A repeated measures analysis of variance (ANOVA) with post-hoc corrections was used to assess changes in PROMs and ROM over time. A p-value of < 0.05 was considered statistically significant. All statistical analyses were performed using GraphPad Prism V9.0 (GraphPad Software, USA).

3. INCLUSION AND EXCLUSION CRITERIA

A rigorous set of criteria was established to ensure a homogenous study population suitable for the evaluation of the rehabilitation protocol.

Inclusion Criteria:

Age between 50 and 85 years.

Primary diagnosis of osteoarthritis requiring a primary, unilateral total knee arthroplasty.

Scheduled to undergo the calipered kinematic alignment surgical technique.

Ability to provide informed consent and participate in the full follow-up schedule.

Medically cleared for major lower extremity surgery.

Exclusion Criteria:

Diagnosis of inflammatory arthritis (e.g., rheumatoid arthritis).

Previous major surgery on the ipsilateral knee, including high tibial or femoral osteotomy.

Severe coronal plane deformity ($\geq 15^\circ$ Varus or valgus) requiring a constrained prosthesis.

Fixed flexion deformity greater than 20° .

Morbid obesity with a Body Mass Index (BMI) of ≥ 40 kg/m².

Presence of significant neuromuscular deficits affecting the operative limb.

Active local infection or systemic sepsis.

Patients requiring the use of intramedullary stems for fixation.

4. RESULTS

Patient Demographics A total of 60 patients who met the eligibility criteria were enrolled and completed the 6-month follow-up. The cohort consisted of 35 females (58%) and 25 males (42%), with a mean age of 67.8 years (SD 8.1). The mean preoperative BMI was 31.2 kg/m² (SD 4.5). Detailed demographic data are presented in Table 1.

Table 1: Baseline Demographics and Clinical Characteristics of the Study Cohort (n=60)

Variable	Data
Mean Age, yrs (SD; range)	67.8 (8.1; 51–84)
Sex, M:F, %	42:58
Side, Left:Right, %	48:52
Mean Preoperative BMI, kg/m ² (SD)	31.2 (4.5)
Mean Preoperative HKA Angle, degrees (SD)	4.5° Varus (3.8)
Mean Preoperative Flexion, degrees (SD)	108 (12.5)
Mean Preoperative Extension Lag, degrees (SD)	5.2 (3.1)

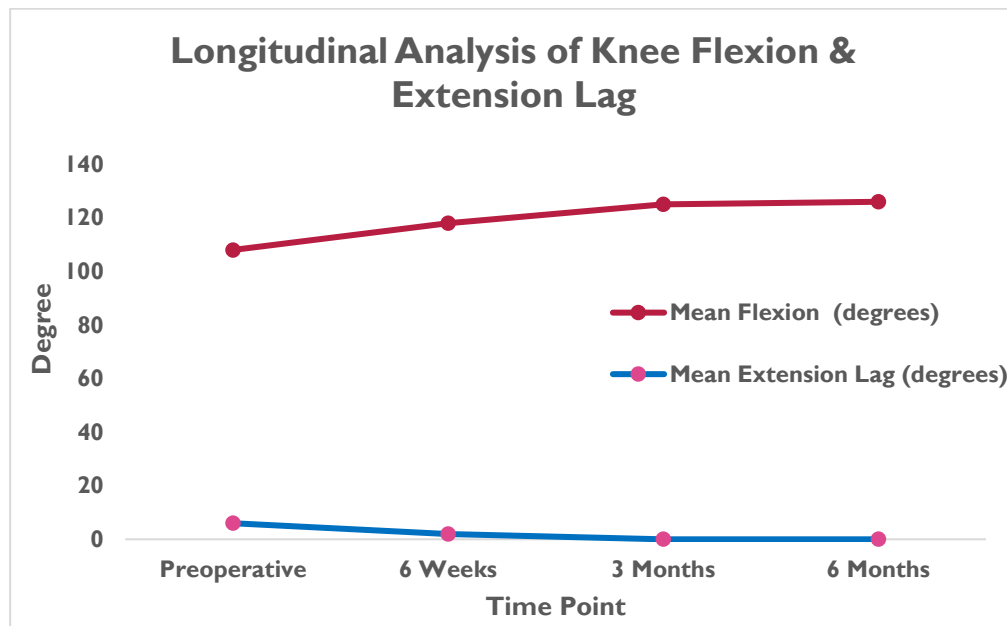
Patient-Reported Outcome Measures (PROMs) The implementation of the specialized rehabilitation protocol resulted in statistically significant improvements across all PROMs at every follow-up interval compared to the preoperative baseline ($p < 0.001$). The mean KOOS sub scores, KSS, and FJS showed substantial gains, with continued improvement observed between the 6-month and 6-month time points for the FJS ($p = 0.015$) and KOOS Quality of Life subscale ($p = 0.021$). Longitudinal PROM data are summarized in Table 2.

Table 2: Longitudinal Analysis of Patient-Reported Outcome Scores

PROMs	Preoperative, mean (SD)	6 Weeks, mean (SD)	3 Months, mean (SD)	6 Months, mean (SD)	p-value*
KOOS Pain	35.8 (16.2)	75.1 (12.8)	88.3 (10.1)	92.4 (8.9)	<0.001
KOOS Symptoms	41.2 (18.5)	70.3 (15.1)	85.9 (11.7)	89.1 (10.4)	<0.001
KOOS ADL	39.0 (17.7)	76.8 (13.4)	89.5 (9.8)	93.0 (8.1)	<0.001
KOOS QoL	20.1 (15.9)	65.4 (19.8)	78.9 (18.2)	84.5 (17.1)	<0.001
KSS Knee Score	45.3 (13.1)	80.1 (10.9)	91.4 (8.3)	95.2 (6.5)	<0.001
KSS Function Score	48.8 (18.8)	72.5 (15.5)	86.6 (12.3)	90.7 (10.9)	<0.001
Forgotten Joint Score	N/A	35.2 (25.1)	61.3 (22.8)	72.5 (18.8)	<0.001
VAS Pain (Activity)	7.5 (1.9)	2.8 (1.5)	1.4 (1.1)	0.8 (0.9)	<0.001

*p-value reflects the significance of change from preoperative to 6 months.

Objective Clinical Outcomes Significant improvements in objective functional measures were observed. Mean active knee flexion increased from 108° preoperatively to 125° at 6 months, and this was maintained at the 6-month follow-up. Full knee extension (0°) was achieved by 96% of patients by the 6-week mark. The trajectory of ROM improvement is illustrated in figure 1.

Fig. 1: Mean active knee flexion and extension lag improvement over the 6-month follow-up period.

Functional milestones were achieved at an accelerated rate compared to historical cohorts undergoing MA TKA. By 2 weeks post-surgery, 37% (55/24) of patients were ambulating independently without any assistive device, and 34% (51/24) could ascend and descend stairs reciprocally.

Complications The rehabilitation protocol was well-tolerated. There were no cases of implant loosening, subsidence, periprosthetic fracture, or deep infection. Five patients (3.3%) reported anterior knee pain that resolved with targeted VMO strengthening and patellar taping. Three patients (2.0%) required manipulation under anaesthesia for stiffness, all of whom subsequently achieved functional ROM.

5. DISCUSSION

This study is the first to formally propose and prospectively evaluate a specialized rehabilitation protocol for patients undergoing primary TKA with kinematic alignment. The findings demonstrate that a structured, phased approach emphasizing early mobilization and targeted strengthening is safe and leads to excellent early functional recovery, significant improvements in PROMs, and a high degree of patient satisfaction.

The rationale for developing a KA-specific protocol is rooted in the fundamental biomechanical differences between KA and MA. Unlike MA, the KA technique preserves the native soft-tissue envelope and collateral ligament laxity, avoiding the need for releases. This inherent stability and preservation of physiological kinematics theoretically permits a more aggressive and accelerated rehabilitation without compromising the implant. Our protocol's emphasis on immediate weight-bearing as tolerated is supported by this principle and by long-term survivorship studies of KA TKA that have shown no increased risk of aseptic loosening, even with tibial components placed in constitutional Varus. The rapid weaning from assistive devices and early return to functional activities observed in our cohort support the hypothesis that KA facilitates faster recovery.

A key finding was the substantial and rapid improvement across a broad range of PROMs. The scores achieved by our cohort at 3 months and 6 months are consistent with the excellent outcomes reported in designer surgeon series of KA TKA. The high FJS scores at 6 months are particularly noteworthy, as this metric is designed to assess a patient's ability to "forget" their artificial joint, a key indicator of a successful TKR. This suggests that the combination of a KA procedure with a tailored rehabilitation plan can lead to a knee that feels more natural to the patient, aligning with one of the primary goals of the KA philosophy.

An important component of our proposed protocol was the proactive focus on patellofemoral health. Some studies have reported a higher incidence of patella-related complications or revisions with early KA techniques using specific instrumentation. While the exact cause is debated, it highlights a potential area of concern. Our protocol incorporated early and consistent VMO activation, patellar mobilization, and neuromuscular control exercises. The low incidence of anterior knee pain (3.3%, all resolving with conservative care) in our cohort suggests that such a targeted approach may be effective in mitigating patellofemoral symptoms postoperatively.

This study has several strengths, including its prospective, multicentre design, the use of a standardized protocol and validated outcome measures, and a 100% follow-up rate. However, certain limitations must be acknowledged. First, there was no randomized control group of patients undergoing MA TKA or KA TKA with a generic rehabilitation protocol. Therefore, we cannot definitively conclude that our protocol is superior to other rehabilitation strategies, although our results compare favourably to historical controls. Second, the follow-up period was limited to six months. While this is sufficient for evaluating early recovery, longer-term studies are needed to assess the maintenance of these outcomes and implant survivorship. Finally, while the protocol is structured, individual patient progress will always vary, and skilled physical therapists are essential for adapting the program to each patient's needs.

In conclusion, this study provides a crucial first step toward establishing evidence-based rehabilitation guidelines for the growing population of patients undergoing KA TKA. The proposed four-phase protocol, which is aligned with the unique biomechanical advantages of the surgical technique, was demonstrated to be safe and highly effective. It facilitated rapid functional recovery, excellent clinical outcomes, and a low complication rate. We advocate for the adoption of these or similar KA-specific guidelines to standardize postoperative care and help patients fully realize the benefits of a kinematically aligned knee.

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