



Predictive Value of Knee Flexion at Hospital Discharge for 6-Month Outcomes Following Total Knee Arthroplasty: A Prospective Cohort Study

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Purpose: To evaluate whether discharge knee flexion $<90^\circ$ after total knee arthroplasty (TKA) predicts 6-month functional outcomes and how postoperative ROM association with final outcomes evolves.

Methods: In this single-center prospective cohort, 216 of 300 patients (72.0%; mean age 68.9 years, 87.0% women) completed 6-month follow-up after primary TKA and were classified by discharge ROM as $<90^\circ$ ($n=32$) or $\geq 90^\circ$ ($n=184$). ROM was measured preoperatively, at discharge, 2 weeks, 6 weeks, 3 months, and 6 months. The primary outcome was 6-month knee flexion ROM. Secondary analyses examined the association between ROM at different postoperative time points and final ROM outcomes. Functional outcomes included the Knee Society Score (KSS) and Oxford Knee Score (OKS).

Results: Six-month ROM ($116.4 \pm 9.7^\circ$ vs $119.0 \pm 7.0^\circ$, $p=0.152$), KSS (94.9 ± 5.7 vs 96.2 ± 7.4 , $p=0.280$), and OKS (38.3 ± 4.8 vs 38.3 ± 5.7 , $p=0.996$) were similar between the $<90^\circ$ and $\geq 90^\circ$ groups, and all patients reached $\geq 90^\circ$ flexion. Discharge ROM weakly predicted 6-month ROM ($R^2=0.026$), whereas 3-month ROM was strongly associated with 6-month ROM ($R^2=0.591$, $\beta=0.643$, 95% CI 0.564–0.722). In multivariable regression adjusted for age, sex, and BMI, preoperative ROM independently predicted 6-month ROM ($p<0.001$), discharge ROM group did not ($p=0.149$).

Conclusions: Discharge ROM $<90^\circ$ did not predict poor 6-month outcomes. Among the time points assessed, 3-month ROM was the strongest predictor of 6-month ROM and may be a useful time point for prognostication.

Keywords: Total knee arthroplasty, range of motion, discharge criteria, predictive value, rehabilitation timing

Total knee arthroplasty (TKA) is highly effective for end-stage knee osteoarthritis, with functional recovery of knee flexion range of motion

(ROM) being a crucial postoperative outcome^(9,11,15). Current guidelines recommend achieving $\geq 90^\circ$ knee flexion before discharge, based on the assumption that this threshold predicts superior long-term outcomes^(2,16).

This practice is now embedded in hospital quality indicators and discharge protocols, often resulting in extended hospital stays and intensive interventions for patients who do not achieve $\geq 90^\circ$ flexion^(2,3,10). However, evidence supporting this threshold remains limited, and the relationship between ROM at different time points and final

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outcomes has not been systematically evaluated (1,8,10).

At our center, the Department of Orthopaedic Surgery established that patients should achieve $\geq 90^\circ$ flexion before discharge, making this a key performance indicator despite the lack of systematic validation of its predictive validity. Determining whether this threshold meaningfully predicts outcomes is essential for evidence-based practice.

The physiological rationale for early ROM assessment is questionable. Postoperative pain, swelling, and tissue healing naturally limit early ROM regardless of intervention intensity, suggesting early measurements may not reflect final functional potential (13, 14). The time point at which ROM measurements become clinically meaningful remains unexplored.

This study addresses two clinical questions: 1) Does discharge ROM $< 90^\circ$ predict poor functional outcomes at 6 months after TKA? and 2) At what time points do ROM measurements become accurate predictors of final outcomes? These questions have immediate implications for clinical protocols, resource allocation, and patient counseling.

MATERIALS AND METHODS

Study Design and Setting

This prospective cohort study was conducted at the Department of Orthopaedic Surgery of the Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand, between January 2017 and December 2023. The study protocol was approved by the Siriraj Institutional Review Board (SIRB) (certificate of approval no. 630/2016), and all participants provided written informed consent to participate in this study.

Participants

The inclusion criteria were: (1) age ≥ 50 years; (2) primary knee osteoarthritis; (3) first-time unilateral TKA; and (4) preoperative knee flexion ROM $\geq 90^\circ$. The exclusion criteria were: (1) surgical complications affecting knee flexion ROM, such as fracture, ligament rupture, or infection; (2) revision TKA; (3) bilateral lower limb pathology; (4) cogni-

tive impairment (Mini-Mental State Examination score < 24); or (5) body mass index (BMI) > 35 kg/m².

Sample Size Calculation

Based on correlations between discharge and 6-month ROM reported by Naylor et al. ($r \approx 0.3$) (8), we calculated a minimum required sample size of 200 patients to detect medium effect sizes ($r = 0.3$) with 80% power and alpha level of 0.05. Assuming potential attrition of 20%, we aimed to enroll 250 patients and ultimately enrolled 300, consistent with the target approved by the Institutional Review Board (certificate of approval no. 630/2016). However, attrition at the 6-month primary endpoint was higher than originally anticipated (84 patients, 28.0%, vs. the anticipated 20%), primarily because patients were lost to follow-up (missed or unable to attend the 6-month clinical visit) over the extended 2017–2023 enrollment period. This is addressed as a study limitation below.

Surgical Procedure and Rehabilitation

Four senior orthopedic surgeons with subspecialty training in joint replacement performed all operations, using a medial parapatellar approach and the same measured-resection surgical technique. Cemented posterior-stabilized prostheses of the same implant design were implanted in all cases, and a pneumatic tourniquet was applied at 250–300 mmHg and maintained throughout each procedure. Postoperative management followed standardized institutional protocols, including multimodal pain control, early patient mobilization, and structured rehabilitation progression.

All patients received a standardized rehabilitation program consisting of hospital-based physiotherapy beginning on postoperative day 1, including gentle ROM exercises, strengthening, and mobility training. The program incorporated an 11-exercise protocol designed to target quadriceps strengthening, ROM improvement, and functional mobility. Patients received comprehensive home exercise instructions and compliance-monitoring diaries, and outpatient physiotherapy follow-up sessions were ordered as clinically indicated.

Outcome Measurements

The primary outcome was knee flexion ROM at 6 months. Secondary outcomes included functional scores (KSS and OKS), ROM progression over time, and exploratory analyses examining associations between ROM measured at different postoperative time points and final ROM outcomes, the proportion of patients achieving functional ROM thresholds of $\geq 90^\circ$ and $\geq 110^\circ$, and the evolution of predictive accuracy (R^2) over time.

Functional Outcome Measures

The Knee Society Score (KSS) is a validated instrument assessing knee-specific function on a 0–100 scale, with higher scores indicating better function. The functional component evaluates walking distance and stair-climbing ability. A score ≥ 90 indicates excellent function, and the minimal clinically important difference (MCID) is approximately 5–10 points.

The Oxford Knee Score (OKS) is a patient-reported outcome measure consisting of 12 questions, with total scores ranging from 0 to 48, where higher scores indicate better outcomes. The OKS has demonstrated excellent internal consistency reliability (Cronbach's $\alpha > 0.9$) and validity in TKA populations, with an MCID of approximately 5 points.

ROM Measurement Protocol

Knee flexion ROM was measured using a standard 12-inch plastic universal goniometer by trained physiotherapists following a standardized protocol. Patients were positioned supine with the hip in neutral position. The goniometer axis was aligned with the lateral femoral epicondyle, the stationary arm was aligned with the lateral midline of the femur toward the greater trochanter, and the moving arm was aligned with the lateral midline of the fibula toward the lateral malleolus. Maximum active knee flexion from full extension (0°) was recorded. All measurements were performed by the same team of physiotherapists to ensure consistency. ROM was assessed preoperatively, at hospital discharge, and at 2 weeks, 6 weeks, 3 months, and 6 months postoperatively.

Statistical analysis

Patients were classified into two groups based on their discharge ROM: $<90^\circ$ or $\geq 90^\circ$.

Between-group comparisons at each time point were performed using independent t tests for continuous variables and chi-square tests for categorical variables. To formally evaluate the ROM recovery trajectory over time while accounting for within-subject correlation and to test whether the rate of recovery differed between groups, a linear mixed-effects model (LMM) was additionally fitted with ROM as the dependent variable; time point (discharge, 2 weeks, 6 weeks, 3 months, 6 months) and discharge ROM group as fixed effects, their interaction term, and a random intercept for each patient. This model used all available longitudinal observations under a missing-at-random assumption without requiring listwise deletion. The group $\times$ time interaction was tested using a likelihood ratio test comparing models with and without the interaction term.

Association analysis: Linear regression analysis was performed with ROM at each time point (preoperative, discharge, 2 weeks, 6 weeks, and 3 months) as the predictor variable and 6-month ROM as the outcome variable, reporting unstandardized regression coefficients (β), coefficients of determination (R^2), and 95% confidence intervals. Pearson correlation coefficients (r) were calculated as descriptive statistics characterizing the strength of linear relationships. Correlation strength was classified as weak ($r < 0.3$), moderate ($0.3 \leq r < 0.7$), or strong ($r \geq 0.7$). Because preoperative ROM is a recognized predictor of postoperative ROM recovery⁽¹²⁾, a multivariable linear regression model was additionally performed with 6-month ROM as the dependent variable and preoperative ROM, discharge ROM group, age, BMI, and sex entered as covariates to determine whether discharge ROM group remained independently associated with 6-month ROM after adjustment for these clinically relevant confounders.

Diagnostic accuracy analysis: To evaluate the clinical utility of ROM thresholds for identifying patients requiring intervention, we calculated diagnostic accuracy parameters, including sensitivity, specificity, positive predictive value (PPV),

and negative predictive value (NPV). These metrics assess how accurately specific ROM cutoffs identify patients at risk of poor functional outcomes, defined as ROM $<110^\circ$ at 6 months, representing suboptimal functional ROM. Secondary analyses included ROM progression analysis and comparison of functional scores (KSS and OKS) between groups. A p -value <0.05 was considered statistically significant. All analyses were performed using SPSS version 28.0 (SPSS, Inc., Chicago, IL, USA).

Analyses at different postoperative time points were performed as exploratory models to evaluate whether ROM measured at each specific time point was associated with final ROM outcomes. These analyses were not intended as repeated hypothesis testing but rather to describe how the strength of association evolved throughout the postoperative recovery period.

RESULTS

Patient Characteristics

Of 300 patients enrolled, 216 completed 6-month follow-up (Fig. 1), yielding a 72.0% follow-up rate at 6 months. Baseline characteristics are presented in Table 1. Overall mean age was 68.9 ± 7.9 years, 87.0% of patients were women, and mean BMI was 27.6 ± 4.4 kg/m². At discharge, 32 patients (14.8%) achieved $<90^\circ$ flexion, whereas 184 (85.2%) had achieved $\geq 90^\circ$. The groups were similar at baseline, including preoperative ROM ($110.2 \pm 16.5^\circ$ vs. $115.4 \pm 14.4^\circ$; $p = 0.098$), although preoperative

ROM was retained a priori as a covariate in the multivariable analysis given its recognized prognostic importance.

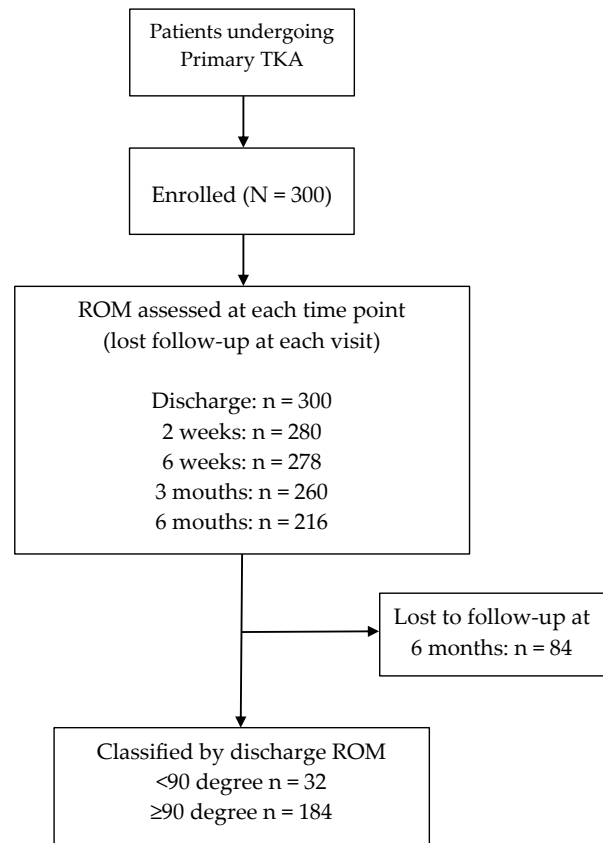


Fig. 1 Patient Flow Diagram.

Table 1 Baseline Characteristics.

Characteristics	Total	$<90^\circ$ Group	$\geq 90^\circ$ Group	p -value
Age (years)	68.9 ± 7.9	67.2 ± 7.5	69.2 ± 7.9	0.172
Women, n (%)	188 (87.0%)	29 (90.6%)	159 (86.4%)	0.712
BMI (kg/m ²)	27.6 ± 4.4	28.1 ± 4.3	27.5 ± 4.4	0.495
Preoperative ROM ($^\circ$)	114.6 ± 14.8	110.2 ± 16.5	115.4 ± 14.4	0.098

Data presented as mean $\pm$ SD or n (%)

Abbreviations: $^\circ$, degrees; BMI, body mass index; kg/m²; ROM, range of motion

Discharge Knee Flexion ROM Threshold Analysis

Patients with discharge ROM $<90^\circ$ achieved 6-month outcomes comparable to those with $\geq 90^\circ$ (Table 2). The 2.6° difference between

groups was neither statistically significant ($p = 0.152$) nor clinically meaningful (effect size, $d = 0.35$), and all patients in both groups achieved $\geq 90^\circ$ flexion by 6 months.

Functional outcomes analysis demonstrated similar patterns between the $<90^\circ$ and $\geq 90^\circ$ groups. The Knee Society Score (KSS) at 6 months showed no significant difference between groups

(94.9 ± 5.7 vs. 96.2 ± 7.4 , respectively; $p = 0.280$), and the Oxford Knee Score (OKS) results were also comparable between groups (38.3 ± 4.8 vs. 38.3 ± 5.7 , respectively; $p = 0.996$).

Table 2 Six-month mean knee flexion ROM outcomes compared between the $<90^\circ$ and $\geq 90^\circ$ groups.

Outcome	$<90^\circ$ Group (n=32)	$\geq 90^\circ$ Group (n=184)	Mean difference (95%CI)	p-value	Effect size (d)
6-month ROM	$116.4 \pm 9.7^\circ$	$119.0 \pm 7.0^\circ$	2.6 (-0.9 to 6.1)	0.152	0.35
KSS score	94.9 ± 5.7	96.2 ± 7.4	1.3 (-1.0 to 3.6)	0.280	0.18
OKS score	38.3 ± 4.8	38.3 ± 5.7	0.0 (-1.9 to 1.9)	0.996	0.00

Data presented as mean $\pm$ SD

Abbreviations: CI, confidence interval; KSS, Knee Society Score; OKS, Oxford Knee Score; ROM, range of motion; SD, standard deviation.

Knee Flexion ROM Recovery Patterns

ROM progression over time demonstrated a "catch-up effect" in the $<90^\circ$ group (Table 3). Denominators at each time point in Table 3 represent all available patients measured at that specific visit (e.g., $n = 41/259$ at discharge, $N = 300$), whereas $n = 32/184$ represents the primary analytic cohort completing 6-month follow-up ($N = 216$). Although the groups differed significantly at discharge ($p < 0.001$), the between-group difference remained statistically significant at 2 weeks ($p =$

0.006) and 6 weeks ($p = 0.005$), narrowed progressively, and became nonsignificant by 3 months ($p = 0.728$), remaining nonsignificant at 6 months ($p = 0.152$). This pattern was confirmed by a linear mixed-effects model, which showed a significant group $\times$ time interaction (likelihood ratio test, $p < 0.001$), formally supporting a differential rate of recovery between groups. The $<90^\circ$ group gained 40.5° from discharge to 6 months, compared with 23.1° in the $\geq 90^\circ$ group, indicating accelerated recovery in patients with lower discharge ROM.

Table 3 Knee flexion ROM values compared between the $<90^\circ$ and $\geq 90^\circ$ groups at different time points from hospital discharge to 6 months after arthroplasty.

Time point	$<90^\circ$ Group	$\geq 90^\circ$ Group	Mean difference	p-value
Discharge (n=41/259)	76.2 ± 6.9	96.4 ± 7.6	20.2°	<0.001
2 weeks (n=40/240)	95.1 ± 13.8	101.7 ± 10.9	6.6°	0.006
6 weeks (n=38/240)	106.1 ± 11.8	112.0 ± 9.3	6.0°	0.005
3 months (n=33/227)	116.2 ± 7.6	115.7 ± 8.9	-0.5°	0.728
6 months (n=32/184)	116.4 ± 9.7	119.0 ± 7.0	2.6°	0.152

Data presented as mean $\pm$ SD, * Denominators reflect all available participants evaluated at each respective timepoint (total $N=300$ at discharge), whereas $n=32$ and $n=184$ represent participants in the $<90^\circ$ and $\geq 90^\circ$ groups who completed the 6-month primary endpoint evaluation ($N=216$)

Abbreviations: ROM, range of motion; SD, standard deviation.

Association Between ROM Measurements and 6-Month Outcomes

Linear regression analyses demonstrated that the strength of association between ROM measurements and 6-month outcomes increased progressively over the postoperative recovery

period (Table 4). Discharge ROM showed only a weak association with final ROM ($\beta = 0.118$, 95% CI 0.020–0.216, $R^2 = 0.026$, $p = 0.019$), explaining only a small proportion of the variance in 6-month ROM outcomes. The strength of the association increased at later postoperative time points. ROM measured

at 2 and 6 weeks demonstrated moderate associations with final ROM outcomes, explaining 18.5% and 31.6% of the outcome variance, respectively.

The strongest association was observed for ROM measured at 3 months ($\beta = 0.643$, 95% CI 0.564–0.722, $R^2 = 0.591$, $p < 0.001$), which explained 59.1% of the variance in 6-month ROM outcomes. Pearson correlation coefficients showed a similar pattern, with progressively stronger linear relationships observed as postoperative recovery progressed. In the multivariable regression analysis ($n = 210$) with 6-month ROM as the dependent variable and preoperative ROM, discharge ROM

group, age, BMI, and sex as covariates, preoperative ROM remained an independent predictor ($\beta = 0.163$, $p < 0.001$), whereas discharge ROM group was not independently associated with 6-month ROM after adjustment ($\beta = 2.02$, $p = 0.149$). Age, BMI, and sex were also not independently associated with 6-month ROM (all $p > 0.1$). These findings indicate that the univariate association between discharge ROM group and 6-month outcomes was substantially explained by preoperative ROM rather than representing an independent predictive effect of discharge status itself.

Table 4 Association between ROM at different time points and 6-month ROM outcomes.

Timepoint	β (95% CI)	R^2	r	p-value
Preoperative	0.163 (0.098–0.227)	0.105	0.323	<0.001
Discharge	0.118 (0.020–0.216)	0.026	0.160	0.019
2 weeks	0.274 (0.194–0.354)	0.185	0.430	<0.001
6 weeks	0.425 (0.337–0.514)	0.316	0.562	<0.001
3 months	0.643 (0.564–0.722)	0.591	0.769	<0.001

Abbreviations: β = unstandardized regression coefficient from simple linear regression models., R^2 = proportion of variance in 6-month ROM explained by ROM measured at each timepoint., Pearson correlation coefficients are reported as descriptive statistics to characterize the strength of linear relationships between ROM measurements at different time points.; ROM, range of motion

Predictive Accuracy of ROM Thresholds for Clinical Decision-Making

Discharge ROM $<90^\circ$ showed a sensitivity of 35.7%, specificity of 86.6%, positive predictive value (PPV) of 15.6%, and negative predictive value (NPV) of 95.1%. ROM $<110^\circ$ at 3 months showed a sensitivity of 100.0%, specificity of 94.2%, PPV of 44.4%, and NPV of 100.0%, confirming 3 months as the optimal time point for clinical assessment and intervention planning.

Diagnostic Accuracy of Discharge ROM Threshold

Diagnostic accuracy analysis showed that discharge ROM $<90^\circ$ had limited ability to identify patients with suboptimal ROM ($<110^\circ$) at 6 months. The sensitivity and PPV of this threshold were low, although specificity was moderate and NPV was high, indicating that a low discharge ROM does not reliably identify patients who will have poor

outcomes, whereas a discharge ROM $\geq 90^\circ$ reliably rules out poor 6-month outcomes.

In contrast, ROM measured at 3 months demonstrated substantially higher sensitivity, specificity, and NPV, suggesting that this time point provides a more clinically meaningful assessment of recovery and prognosis, particularly for identifying patients at risk of poor 6-month outcomes.

DISCUSSION

The findings of this prospective cohort study challenge fundamental assumptions underlying current post-TKA care guidelines by demonstrating that discharge ROM $<90^\circ$ does not predict poor 6-month outcomes and that ROM predictive values change substantially over time during the early postoperative ROM assessment timeline. Our finding that discharge knee flexion ROM showed

the weakest association with final outcomes among all time points studied has immediate implications for clinical practice. Furthermore, the finding that ROM measured at 3 months demonstrated the strongest association with final ROM outcomes provides evidence-based guidance for intervention timing.

Challenge to Current Discharge ROM Criteria

The equivalent outcomes achieved by patients with discharge ROM $<90^\circ$ and those with discharge ROM $\geq 90^\circ$ directly challenge the widespread use of this threshold as a post-TKA hospital discharge criterion. These findings are consistent with previous research by Naylor *et al.*, who reported weak correlations between early and late ROM outcomes, although their work focused primarily on correlation strength rather than clinical implications⁽⁸⁾. Interestingly, the 90° discharge threshold serves as a key performance indicator at our center and many other centers worldwide despite its lack of demonstrated predictive validity. Both groups in our study achieved excellent 6-month ROM outcomes, with 100% of patients achieving $\geq 90^\circ$ flexion and nearly 94% achieving functional ROM $\geq 110^\circ$.

The 'catch-up effect' observed in patients with knee flexion ROM $<90^\circ$ at hospital discharge suggests that early limitations reflect temporary factors rather than permanent dysfunction. This finding is supported by rehabilitation research demonstrating that ROM recovery occurs naturally over time regardless of early intervention intensity⁽¹⁾. Postoperative pain, swelling, and interindividual variation substantially influence early measurements but do not necessarily determine final outcomes. These findings support a more patient-centered approach to discharge planning that focuses more on safety parameters than on arbitrary ROM thresholds.

Evidence for Delayed Assessment Timing

The progressive improvement in ROM predictive value from discharge (2.6% variance explained) to 3 months (59.1% variance explained) reveals a clear physiological timeline for meaningful assessment. Our finding that preoperative ROM

was more predictive than discharge ROM ($R^2 = 0.105$ vs. $R^2 = 0.026$) and remained an independent predictor of 6-month ROM on multivariable analysis after adjustment for discharge ROM group, age, BMI, and sex underscores the limitations of early postoperative measurements. It also suggests that baseline patient characteristics may be more informative than acute postoperative characteristics.

A systematic review of controlled trials of post-TKA rehabilitation found that early aggressive interventions may not improve outcomes compared with standard care protocols⁽¹⁰⁾. Our findings provide quantitative evidence supporting this theory by demonstrating that early ROM measurements lack predictive value for clinical decision-making. The identification of 3 months post-TKA as the first time point providing accurate prediction has important implications for intervention timing, as current practices emphasizing early aggressive interventions for patients with poor postoperative knee flexion ROM may not be evidence-based and lack scientific foundation.

Clinical Practice Implications

The findings of the present study support a comprehensive review and revision of current post-TKA care protocols. A study of manipulation under anesthesia demonstrated that the timing of intervention significantly influences outcomes, with procedures performed too early yielding comparatively limited benefit⁽⁶⁾. Our data suggest that the 3-month threshold time point provides evidence-based guidance for when clinical concerns about ROM become more justified and when intervention decisions can be made with confidence.

The timing of ROM assessment requires reconsideration based on the physiology of healing. During the acute inflammatory phase, ROM limitations reflect normal tissue responses rather than functional problems^(5,13). The progressive improvement in predictive accuracy aligns with tissue maturation timelines, suggesting that clinical assessment should follow physiological healing patterns rather than arbitrary schedules.

Moreover, resource allocation can be improved by concentrating rehabilitation efforts

during periods when ROM becomes more predictive rather than immediately after surgery. Studies examining the cost-effectiveness of early intensive rehabilitation have questioned the value of aggressive early interventions, supporting a more measured approach to resource utilization⁽¹⁰⁾. This proposed approach could potentially improve cost-effectiveness while maintaining or improving patient outcomes.

Physiological Rationale

The temporal evolution of predictive value aligns with known healing physiology and may explain the observed patterns⁽¹³⁾. During the acute inflammatory phase (0–2 weeks), acute inflammation, pain, and swelling dominate early recovery, thereby inhibiting or masking true ROM potential⁽⁵⁾. High individual variation in the inflammatory response explains the poor predictive value of early measurements^(5, 13). The proliferative phase (2–6 weeks) involves tissue healing and cellular repair, with gradual improvement in ROM predictive value as acute factors resolve and muscle function begins to recover⁽⁷⁾.

The maturation phase (6 weeks to 3 months) is characterized by tissue remodeling and strength recovery, facilitating more accurate ROM assessment^(7, 13). The 3-month threshold observed in this study aligns with the completion of initial tissue maturation and the beginning of the stable phase (3–6 months), when ROM becomes stable and accurately predictive of long-term outcomes⁽¹³⁾.

Strengths and Limitations

This study has several methodological strengths. First, its prospective design eliminates recall bias and ensures standardized data collection. Second, this is the first systematic evaluation of how ROM predictive value changes over time after TKA, addressing an important knowledge gap. Third, the sample size (216 patients with complete 6-month follow-up) exceeds the calculated minimum and provides robust statistical power. Fourth, the findings have immediate clinical applicability to discharge guidelines and care protocols.

Several limitations must be considered. First, the single-center design at a large tertiary

referral center may limit generalizability across healthcare settings and patient populations. Second, this exceeded our IRB-anticipated attrition of 20%: 84 of 300 enrolled patients (28.0%) did not have ROM data at 6 months, predominantly because patients did not return for or could not be reached for the 6-month follow-up visit over our extended 2017–2023 enrollment period, and were therefore not included in the primary analysis. Although the possibility of attrition bias cannot be excluded if patients lost to follow-up differed systematically in their recovery. Third, although all patients received standardized rehabilitation protocols, variations in adherence may have influenced recovery trajectories. Fourth, we excluded patients with surgical complications affecting knee flexion ROM (e.g., fracture, ligament rupture, or infection), who might be at the highest risk of poor postoperative ROM. Because these patients were more likely to experience arthrofibrosis or stiffness, their exclusion may have inflated the apparent recovery observed in the discharge ROM <90° group and may have improved the apparent diagnostic performance of discharge ROM thresholds. This selection bias should therefore be considered when generalizing our findings to patients with complicated postoperative courses.

Regarding statistical methodology, we supplemented the time point-specific independent t tests with a LMM incorporating all available longitudinal ROM measurements, time point, discharge ROM group, and their interaction. This analysis formally confirmed a significant group × time interaction (likelihood ratio test, $p < 0.001$), consistent with the catch-up pattern described above. We also performed a multivariable linear regression adjusting for preoperative ROM, age, BMI, and sex, which showed that discharge ROM group was not independently associated with 6-month ROM ($p = 0.149$) after accounting for preoperative ROM, whereas preoperative ROM remained an independent predictor ($p < 0.001$). Together, these analyses indicate that our principal conclusions—that discharge ROM <90° does not independently predict poor 6-month outcomes and that predictive accuracy improves with later assessment—are robust to the analytical approach used.

Clinical Recommendations

Clinical practice guidelines and protocols should be modified based on these evidence-based findings. Hospital administrators should consider revising policies to remove ROM-specific discharge criteria from institutional protocols and update key performance indicators to reflect evidence-based outcomes rather than early ROM measurements. Resource optimization could be achieved by reallocating intensive rehabilitation resources to periods when ROM assessment becomes predictive, which in this study typically occurred during 6 weeks to 3 months post-TKA. Staff education programs should train healthcare teams on evidence-based ROM assessment timelines and appropriate intervention timing.

Orthopedic surgeons should base discharge decisions on safety and wound healing rather than specific ROM numbers, and patient counseling should educate patients about normal recovery timelines and reduce anxiety related to early ROM limitations. Intervention timing for procedures such as manipulation under anesthesia should be individualized rather than routinely delayed. Our data suggest that 3 months represents the point at which ROM assessment becomes more clinically informative for prognostication; however, this should not be interpreted as evidence that manipulation under anesthesia (MUA) itself should routinely be postponed until this time point, because its timing also depends on factors such as the degree of stiffness, functional impact, and surgeon judgment ⁽⁴⁾, which were not directly evaluated in this study. Follow-up visit scheduling should be optimized based on the evolution of predictive values rather than traditional arbitrary timelines.

Physiotherapists should prioritize pain management, safety, and basic mobility during early rehabilitation rather than aggressive ROM interventions. Progressive intensity could increase as predictive value improves, with concentrated efforts during clinically meaningful assessment periods between 6 weeks and 3 months postoperatively. Patient education should emphasize normal recovery patterns and reduce ROM-related anxiety while encouraging consistent exercise compliance

throughout recovery. Resource allocation should focus on periods when interventions can be guided by more accurate clinical assessment.

CONCLUSION

Discharge knee flexion <90° does not predict poor functional outcomes after TKA. Early ROM measurements provide limited prognostic value, whereas ROM assessed at 3 months is the first accurate and clinically meaningful predictor. These findings support evidence-based revision of discharge criteria and rehabilitation protocols, focusing on gradual recovery rather than arbitrary early thresholds.

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