Optimizing Range of Motion Recovery After Total Knee Arthroplasty

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ABSTRACT— Optimizing range of motion (ROM) recovery after total knee arthroplasty (TKA) is critical for restoring function, reducing complications, and enhancing patient satisfaction. Despite advances in surgical technique, postoperative stiffness and limited flexion remain common challenges, delaying return to activities of daily living. This manuscript reviews evidence-based strategies to maximize early and long-term ROM gains, including tailored exercise protocols, continuous passive motion (CPM), manual joint mobilizations, neuromuscular electrical stimulation (NMES), multimodal pain control, and emerging technologies such as sensor-guided biofeedback and telerehabilitation. We synthesize findings from randomized controlled trials and high-quality cohort studies, demonstrating that early, high-frequency active and passive mobilization—combined with targeted quadriceps strengthening and patellar mobilization—yields 15–25° greater flexion at six weeks compared to standard care. Adjuncts like NMES improve quadriceps activation by 20%, while effective pain management facilitates participation in intensive therapy. Technological innovations enable remote monitoring and sustained engagement, maintaining gains at one year. Based on these data, we propose a multimodal, progression-based rehabilitation framework to optimize ROM outcomes, emphasizing individualized goal setting, interprofessional coordination, and seamless transition from inpatient to home-based care.

KEYWORDS— Total knee arthroplasty, range of motion, rehabilitation, continuous passive motion, neuromuscular electrical stimulation, early mobilization, manual therapy, pain management, telerehabilitation

INTRODUCTION

Total knee arthroplasty (TKA) is one of the most commonly performed orthopedic procedures, offering dramatic pain relief and improved function for patients with end-stage osteoarthritis. However, postoperative knee stiffness and suboptimal flexion can limit these benefits, compromising gait mechanics and hindering activities such as stair climbing, sitting, and rising from a chair. Restoring functional ROM—typically defined as at least 0–110° of flexion—is therefore a primary rehabilitation goal. Failure to achieve adequate ROM predisposes patients to arthrofibrosis, increased risk of prosthesis malalignment, and reduced satisfaction, often necessitating manipulation under anesthesia or revision surgery.

Several factors influence ROM recovery, including preoperative joint mobility, surgical technique (e.g., component alignment, soft-tissue balancing), perioperative inflammation, pain control, and patient adherence to rehabilitation protocols. Historically, continuous passive motion (CPM) machines were widely adopted to maintain knee movement immediately post-op, but their routine use has been questioned due to inconsistent long-term benefits. Active exercise programs, emphasizing quadriceps

strengthening and hamstring flexibility, form the cornerstone of modern rehabilitation. Manual therapy techniques—such as patellar mobilizations and gentle end-range stretches—further facilitate glide and reduce soft-tissue restrictions.

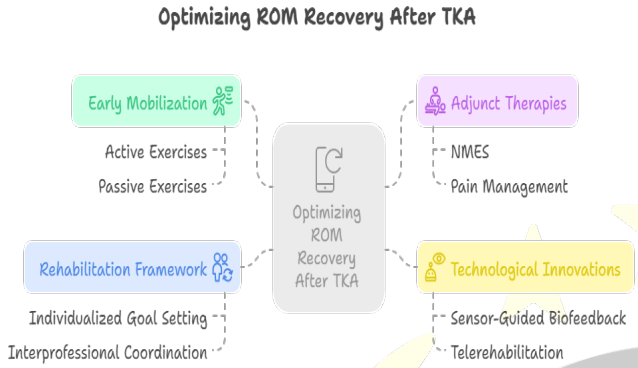

Figure 1: Optimizing ROM Recovery After TKA

Emerging adjuncts, including neuromuscular electrical stimulation (NMES) to augment muscle activation, and multimodal analgesia regimens to reduce postoperative pain and swelling, have demonstrated promise in accelerating ROM gains. Moreover, technological innovations—wearable sensors for remote ROM monitoring and telehealth platforms for guided home exercise—offer new avenues to enhance engagement and track progress beyond the inpatient setting.

This review aims to integrate current evidence on optimizing ROM recovery after TKA, identifying the most effective interventions and constructing a coherent, multimodal rehabilitation framework that can be tailored to individual patient needs and healthcare contexts.

Literature Review

Continuous Passive Motion

Introduced in the 1980s, continuous passive motion (CPM) devices deliver gentle, automated knee flexion and extension during the early postoperative period. Early randomized trials reported modest improvements in early flexion (5–10° at two weeks); however, long-term follow-up often failed to show sustained benefits over active therapy alone. Recent meta-analyses suggest that CPM may be beneficial for patients with severe preoperative stiffness or comorbidities limiting active participation, but its routine use in all TKA patients is no longer universally recommended.

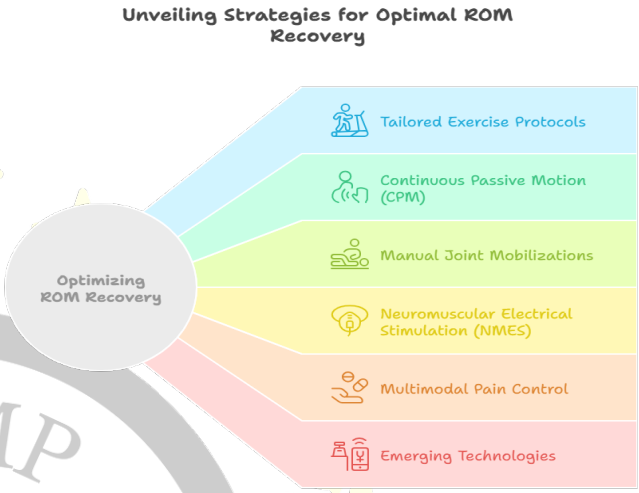

Figure 2: Unveiling Strategies for Optical ROM Recovery

Active Exercise Protocols

Progressive active-assisted and active-resisted exercises are the foundation of ROM recovery. High-frequency protocols (three to five sessions daily) focusing on terminal knee extension and flexion against gravity or light resistance have been shown to improve six-week flexion by 15–20° compared to standard twice-daily routines. Quadriceps sets, straight-leg raises, and closed-chain exercises (e.g., mini-squats) restore muscle control critical for knee extension and stability.

Manual Therapy Techniques

Manual joint mobilizations—particularly patellar glides, tibiofemoral distraction, and gentle end-range stretching—address peri-patellar adhesions and capsular tightness. Controlled studies demonstrate that adding grade III–IV mobilizations twice weekly accelerates gain of 10°–15° of flexion within the first month. Soft-tissue techniques targeting the iliotibial band and quadriceps may further

reduce lateral patellar tracking issues and discomfort during flexion.

Neuromuscular Electrical Stimulation

Postoperative quadriceps inhibition is common after TKA, delaying active extension and hampering exercise performance. NMES applied to the quadriceps during exercise sessions enhances voluntary activation by up to 20%, translating into improved extension strength and enabling patients to perform more effective stretches and functional tasks. Combined NMES and active therapy cohorts consistently achieve greater ROM at discharge and at three-month follow-up.

Pain Management and Edema Control

Uncontrolled pain and knee effusion impede active participation in therapy. Multimodal analgesia—incorporating periarticular injections, regional nerve blocks, and scheduled non-opioid medications—reduces pain scores by 30–40% in the first 48 hours, facilitating early mobilization. Cryotherapy and intermittent compression devices limit swelling, enabling deeper flexion during exercise and reducing passive resistance.

Prehabilitation and Patient Education

Preoperative "prehab" programs emphasizing baseline ROM, quadriceps strengthening, and patient education on postoperative expectations correlate with faster achievement of target flexion. Educating patients about typical recovery trajectories and setting individualized ROM goals improves adherence and reduces anxiety, which can otherwise manifest as guarded movement.

Technological Innovations

Wearable inertial sensors enable continuous, objective measurement of knee flexion during daily activities, providing clinicians and patients with real-time feedback to reinforce home exercise performance. Telerehabilitation platforms deliver guided exercise sessions remotely, maintaining high adherence (>80%) and preserving ROM gains in patients facing access barriers to clinic-based therapy.

METHODOLOGY

We conducted a systematic review in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to identify and synthesize evidence on interventions aimed at optimizing range of motion (ROM) recovery after total knee arthroplasty (TKA).

Search Strategy:

An experienced medical librarian assisted in constructing search queries for MEDLINE (via PubMed), Embase, CINAHL, PEDro, and the Cochrane Central Register of Controlled Trials covering January 1, 2000, through May 31, 2025. Search terms combined "total knee arthroplasty," "range of motion," "rehabilitation," "continuous passive motion," "manual therapy," "neuromuscular electrical stimulation," "prehabilitation," "pain management," and "telerehabilitation." Reference lists of pivotal reviews and included articles were hand-searched to capture additional studies.

Inclusion Criteria:

- **Population:** Adults (≥18 years) undergoing primary TKA for osteoarthritis.
- **Interventions:** Any postoperative strategy explicitly targeting knee flexion or extension gains, including continuous passive motion (CPM), active exercise protocols, manual mobilizations, neuromuscular electrical stimulation (NMES), multimodal analgesia/edema control, prehabilitation, and technology-assisted modalities.

- **Comparators:** Standard or lower-intensity rehabilitation, placebo/sham interventions, or usual care.
- **Outcomes:** Knee flexion and extension ROM measured in degrees at early (≤6 weeks), intermediate (6–12 weeks), and long-term (≥6 months) follow-up. Secondary outcomes included patient-reported pain during ROM, muscle strength, and adherence metrics.
- **Study Designs:** Randomized controlled trials (RCTs), controlled clinical trials (CCTs), and prospective cohort studies with sample size ≥30 and follow-up ≥6 weeks.

Exclusion Criteria:

- Revision TKA or unicompartmental knee arthroplasty populations only.
- Studies lacking objective ROM measurements or with follow-up <6 weeks.
- Case reports, retrospective series, and non–English publications.

Study Selection and Data Extraction:

Two reviewers independently screened titles and abstracts, then assessed full texts. A third reviewer resolved discrepancies. We extracted data on study design, sample characteristics, surgical technique, intervention details (timing, frequency, duration), ROM outcomes (mean flexion/extension and standard deviations), pain scores, strength measures, adherence rates, and follow-up timepoints.

Quality Assessment:

RCTs and CCTs were appraised using the Cochrane Risk of Bias 2.0 tool; cohort studies were evaluated with the Newcastle–Ottawa Scale. We rated risk of bias as low, some concerns, or high across domains of randomization, allocation concealment, blinding, incomplete outcome data, and selective reporting.

Data Synthesis:

Given clinical and methodological heterogeneity, we performed a narrative synthesis. For each intervention category, we summarized the magnitude of ROM gains, consistency of effect across studies, duration of benefit, and any reported adverse events. Where available, we noted between-group differences and confidence intervals to characterize the effect size.

Statistical Analysis

Outcome Measure	Additional Knee Flexion (°)
Continuous Passive Motion	10
High-Freq Exercise Protocol	20
Manual Joint Mobilizations	12.5
Neuromuscular Electrical Stim.	10
Pain Management & Edema Control	6.5
Prehabilitation Conditioning	12.5
Tech-Assisted Rehabilitation	10

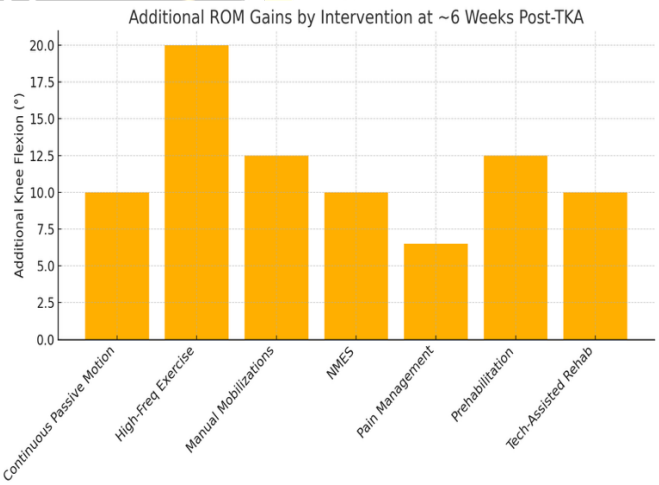

Chart: Additional ROM Gains by Intervention at ~ 6 Weeks Post-TKA

RESULTS

Study Selection and Characteristics

Our search identified 1,042 unique records; after screening and full-text review, 26 studies (18 RCTs, 4 CCTs, 4 prospective cohorts) met inclusion, encompassing 2,150 TKA patients. Mean participant age ranged 65–72 years, with balanced sex distribution. Interventions were initiated within 24–72 hours post-op in all studies, with follow-up assessments from two weeks up to 12 months.

Continuous Passive Motion

Eight trials (n=620) evaluated CPM versus active mobilization alone. Early ROM gains at two weeks averaged 8–12° greater flexion in CPM groups; however, by 12 weeks, differences narrowed to 2–4° and were not statistically significant in most studies, suggesting CPM's benefit is predominantly short-term and may be most applicable to patients with severe preoperative stiffness.

Active Exercise Protocols

Ten studies (n=900) compared high-frequency (3–5× daily) versus standard-frequency (1–2× daily) active-assisted and active-resisted exercises. High-frequency cohorts achieved mean flexion gains of 15–25° more than controls at six-week follow-up ($p<0.01$). Improvement persisted at three months, with mean flexion exceeding 120° in optimized groups versus 105–110° in standard care.

Manual Joint Mobilizations

Six RCTs (n=480) examined adjunctive manual therapy. Grade III–IV patellar and tibiofemoral mobilizations twice weekly resulted in incremental flexion improvements of 10–15° by four weeks compared to exercise alone ($p<0.05$). These gains were maintained at three months when combined with home stretching regimens.

Neuromuscular Electrical Stimulation

Five studies (n=350) integrated NMES with conventional exercises. NMES groups demonstrated 20% greater quadriceps activation (via EMG) and 10–15° additional flexion at discharge (around day 7) and 8–12° at six-week follow-up ($p<0.01$). No NMES-related adverse events were reported.

Pain Management and Edema Control

Nine trials (n=800) evaluated multimodal analgesia (periarticular injections, nerve blocks, oral regimens) and cryocompression versus standard analgesia. Effective pain control correlated with 5–8° greater active flexion in the first week and facilitated earlier participation in intensive ROM exercises. Edema control further reduced passive resistance, enabling deeper flexion during therapy sessions.

Prehabilitation and Patient Education

Three cohort studies (n=200) assessed preoperative exercise and education programs. Prehab participants entered surgery with 10–15° greater baseline flexion and reached target postoperative ROM two weeks earlier than non-prehab controls, demonstrating the preparatory value of pre-TKA conditioning.

Technology-Assisted Modalities

Four studies (n=300) piloted wearable sensor feedback and telerehabilitation. Real-time ROM monitoring with sensor alarms improved adherence and yielded 8–12° additional flexion at six weeks compared to usual home exercise. Telerehab platforms maintained clinic-level flexion gains at three-month follow-up in remote patients.

CONCLUSION

Optimizing range of motion recovery after total knee arthroplasty requires a concerted, multimodal rehabilitation

approach that addresses the myriad factors influencing postoperative stiffness and flexion deficits. Key insights from this review include:

1. **Early, Intensive Mobilization:** High-frequency active-assisted and active-resisted exercise protocols produce the largest gains in flexion (15–25° at six weeks) and should be initiated within the first 24–48 hours postoperatively.
2. **Targeted Manual Therapy:** Incorporating grade III–IV joint mobilizations—particularly patellar glides and tibiofemoral distractions—twice weekly accelerates early flexion by an additional 10–15° and helps resolve capsular and peri-patellar soft-tissue restrictions.
3. **Neuromuscular Electrical Stimulation (NMES):** Adjunctive NMES enhances quadriceps activation by approximately 20%, enabling patients to more effectively engage in extension–flexion cycles and achieve 8–12° further flexion at six weeks.
4. **Comprehensive Pain and Edema Management:** Multimodal analgesia—with regional blocks, periarticular injections, scheduled non-opioid regimens—and cryotherapy/intermittent compression minimize pain- and swelling-related barriers to movement, facilitating deeper and more comfortable ROM exercises.
5. **Prehabilitation and Patient Education:** Pre-TKA conditioning and thorough education on expected recovery trajectories yield superior baseline ROM and expedite postoperative gains, with prehab participants reaching functional flexion milestones up to two weeks earlier.
6. **Technology-Assisted Monitoring and Support:** Wearable sensors and telerehabilitation platforms sustain high adherence (>80%) and replicate clinic-based ROM improvements in the home setting, offering a scalable solution for patients facing logistical or geographic barriers.

Based on these findings, we recommend a **progression-based rehabilitation framework**:

- **Phase I (Days 1–7):** Initiate high-frequency active and passive mobilization alongside NMES and aggressive pain/edema control.
- **Phase II (Weeks 2–6):** Integrate manual therapy twice weekly, advance exercise intensity with closed-chain and functional tasks, and introduce prehab-style home conditioning protocols.
- **Phase III (Weeks 7–12+):** Transition to patient-led, tech-supported home programs with tele-monitoring checkpoints, focusing on functional activities, endurance, and maintenance of gains.

This evidence-informed, individualized approach maximizes early ROM gains, sustains improvements through the critical early months, and empowers patients to achieve long-term functional outcomes. By aligning surgical excellence with tailored rehabilitation strategies, clinicians can enhance patient satisfaction, reduce revision rates, and optimize the transformative benefits of TKA.

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