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Neuromuscular Electrical Stimulation as Prehabilitation for Bilateral Total Knee Arthroplasty: A Pilot Within-Patient Case Series

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Abstract

Quadriceps muscle strength loss after total knee arthroplasty remains a major barrier that impairs functional recovery. Pre-operative rehabilitation has been proposed to enhance this problem, yet existing evidence is inconsistent. Neuromuscular electrical stimulation may offer a feasible option for patients limited by pre-operative pain. This pilot study explored the feasibility and observed recovery trends of a structured NMES-based prehabilitation program before the second TKA in staged bilateral cases. Seven female patients undergoing staged bilateral TKA participated in this prospective within-patient comparative case series. Each patient served as their own control. The first TKA received standard post-operative rehabilitation only, while the in-contralateral knee received a 10-week NMES prehabilitation program before the second TKA. Outcomes included pain intensity (VAS), knee range of motion (ROM), quadriceps muscle strength (MMT), and functional performance (TUG, 6 MWT) were tracked descriptively at baseline, 3,6,12 weeks and 12 months post-operative. Given the pilot nature, data are presented descriptively with individual trajectories. Results showed that from 12 months on prehabilitation knee demonstrated clinically meaningful improvements over postoperative rehabilitation, showed lower pain score, greater knee flexion ROM (112.14 vs 109.29), and quadriceps strength was higher (MMT 4.57 vs 3.57). Six of seven participants showed consistent within-trajectories favoring prehabilitation. The protocol was well-tolerated without adverse events. In this small exploratory pilot case series study, NMES-based prehabilitation before the second TKA was feasible and was associated with a more favorable recovery pattern within the same patients at 12 months. While causal conclusions cannot be made, the within-patient design helps limit inter-individual variability and support further research in larger controlled trials of prehabilitation in TKA recovery.

Keywords: Prehabilitation; Neuromuscular Electrical Stimulation; Total knee arthroplasty; Pilot research.

Abbreviations: TKA-Total knee arthroplasty; KOA-Knee osteoarthritis; QoL-Quality of life; TENS-Transcutaneous Electrical Nerve Stimulation; BMI-Body Mass Index; TKA-Total Knee Artroplasty; PFT-Patellofemoral joint; TFJ-Tibiofemoral joint.

INTRODUCTION

Knee osteoarthritis (KOA) stands as one of the most prevalent and burdensome chronic musculoskeletal degenerative joint disorders worldwide, affecting more than 528 million people in 2021 (Geng et al., 2023). The knee is the most involved joint, accounting for approximately 70% of all osteoarthritis cases. KOA predominantly affects older adults, with prevalence increasing markedly with age (Chen et al., 2025). As the population continues to age, the global demand for total knee arthroplasty (TKA) is expected to rise accordingly. In Indonesia, KOA prevalence represents a growing public health concern, reported at 30% in adults 40-50 years, increasing to 65% in those over 65 years (Badan Kebijakan Pembangunan Kesehatan, 2023). The burden of KOA is escalating with demographic aging and is a leading cause of chronic pain, progressive mobility loss, functional limitation, reduced independence, and diminished quality of life. At a population level, it contributes substantially to years lived with disability (10-12%) (Sunadi et al., 2024). Together, KOA highlighted it as not only a degenerative joint condition, but a major and growing clinical and health-system challenge.

Total knee arthroplasty (TKA) is a gold standard surgical treatment for severe KOA or end-stage disease (Kellgren-Lawrence grade III/IV) with well-established benefits in pain reduction, joint alignment, restoring movement, and improving the quality of life (QoL) (Zimnoch et al., 2025). Total knee arthroplasty (TKA) is widely regarded as a safe, effective, cost-efficient, and consistently successful surgical procedure with reliable outcomes for end-stage degenerative knee OA. Previous research has found that the QoL of patient with TKA improves with functional improvement (Canovas & Dagneaux, 2018). However, despite its success, up to 40-50% of patients continue to experience postoperative

pain, stiffness, restricted joint motion, infection, implant loosening, mechanical problems, instability and muscle weakness, even atrophy and show functional limitation and approximately 53% report chronic pain at one year (Wylde et al., 2018). Notably, early postoperative pain and neuromuscular inhibition often limit effective voluntary muscle activations, suggesting that conventional postoperative rehabilitation alone may be insufficient to fully prevent prolonged quadriceps weakness after TKT.

These conditions highlight the urgency to optimize patients before surgery, not only postoperatively. Preoperative rehabilitation (prehabilitation) is increasingly promoted as a strategy to enhance postoperative outcomes by improving physical conditioning and physiological resilience before TKA. However, the evidence remains inconsistent, some may optimize post-operative outcomes, the other evidence states the opposite result. Results from metanalyses study showed small benefits in early pain, strength and function but the overall impact is modest and short-term (Wang et al., 2026). The heterogeneity of existing pre-rehabilitation programs ranging from 2 to 6 weeks, using various exercise modalities, limit their clinical applicability. Most importantly, the studies rely solely on voluntary exercises, which many patients with severe KOA cannot perform effectively due to pain and joint limitation (Jirakulsawat et al., 2024). Furthermore, evidence comes from unilateral TKA populations, leaving a major gap in understanding prehabilitation in staged bilateral procedures or in long-term postoperative outcomes.

Neuromuscular Electric Stimulation (NMES) is a widely used electrophysical modality that induces muscle contraction by delivering electrical impulses to peripheral nerves, mimicking central nervous system activation. NMES is an excellent modality and commonly applied in postoperative rehabilitation; its role in the preoperative setting remains underexplored. Unlike voluntary exercise, which can be limited by pain, NMES directly activates and increases type II muscle fibers recruitment, mitigating the quadriceps voluntary activation, re-educating muscle contractions, preventing disuse, also improving range of motion, making it a promising modality for patients with severe knee osteoarthritis who experience pain-related movement limitation and quadriceps inhibition (Klika et al., 2022). Conversely, Transcutaneous Electrical Nerve Stimulation (TENS) primarily provides analgesia but is not designed to strengthen muscles. These characteristics make NMES a promising modality for prehabilitation before TKA (Rajamohan et al., 2023).

In Indonesia, research on pre-rehabilitation for TKA is extremely limited. No study has evaluated preoperative NMES in patients scheduled for staged bilateral TKA, one side by one side (interval time between TKA). Additionally, NMES studies have focused on postoperative rehabilitation, leaving a gap in understanding its preoperative benefits. Previous prehabilitation studies have involved unilateral TKA with heterogeneous, often short-duration, exercise protocols. To address these gaps, we employed a within-patient bilateral TKA design, enabling direct comparison while eliminating inter-individual variability. The natural interval between the first and second TKA surgery creates a window for preoperative conditioning. Moreover, a within-patient comparative design where the first TKA as postoperative rehabilitation and the second TKA receives pre-rehabilitation.

This study aims to investigate whether a 10-week pre-operative NMES-based pre-rehabilitation program administered before the second TKA improves postoperative pain, quadriceps muscle range of motion, and functional recovery speed compared with the first TKA that received standard postoperative rehabilitation only. This approach expected to provide valuable preliminary study that NMES pre-rehabilitation can enhance muscle strength, profound quadriceps muscle weakness, improve physical function and speed recovery after TKA procedure.

MATERIALS AND METHODS

Study Design

This study is a prospective case involving seven females undergoing bilateral total knee arthroplasty (TKA) within-patient comparative case series. The study was conducted at a hospital in Kediri, East Java, Indonesia between January 2022 until June 2024. Each participant served as their own control; the first operated knee, received standard post-operative rehabilitation program only, while the contralateral knee received 10-week preoperative NMES based prehabilitation program before undergoing the second TKA. This study design allows direct comparison of the effects of preoperative rehabilitation programs and postoperative rehabilitation programs within the same individual, minimizing inter-individual variability with the same demography.

The study was approved by the Ethics Committee of the Faculty of Health Sciences, Jenderal Soedirman University, and overseen by the Hospital Medical Committee.

Participants

Patients who underwent a primary unilateral TKA in the Orthopedic Department were referred to the Physical Medicine and Rehabilitation Department for 12 weeks postoperative rehabilitation and those who were planned to have another TKA in the contralateral knee, were consecutively referred between January 2022 and June 2024. Patients were included if aged 55-75 years, with end-stage tricompartmental knee osteoarthritis, who had ongoing first post-rehabilitation TKA and were

scheduled for the contralateral TKA within at least 12 weeks. All TKA procedures used a cemented tricompartmental prosthesis via a parapatellar approach. Inclusion criteria were 1) diagnosis of bilateral end-stage KOA (Kellgren-Lawrence grade III-IV), 2) Ability to follow all pre-rehabilitation and rehabilitation guidelines protocol, and 3) provided written informed consent. Exclusion criteria were neuromuscular disease, bone implant, history of lower fractures within six months, cancerous, chronic disease, intra-knee injection in the past six months, morbidity obesity (BMI>40 kg/m2), implanted pacemaker or defibrillator, dermatological conditions affecting the thigh, and unwillingness to participate in this study. All seven female subjects completed the study without complications.

Intervention

The contralateral knee scheduled for the second TKA received a ten-week prehabilitation program consisting of NMES, TENS and therapeutic exercise twice weekly. NMES was applied in the supine position (BTL) to the quadriceps muscle with a Symmetrical biphasic square waveform, Frequency 50 Hz, pulse duration 400 µs, duty cycle 10s on/50s off, and maximum tolerated current for 20 minutes. The electrode patch is attached to the vastus medialis & lateralis. Following NMES, the physiotherapist will guide the patient through straight-leg raise, heel slide, and hip abduction (3 sets with 10 repetitions/set). Five times sit to stand and step up exercise. TENS was applied after exercise for pain modulation using a symmetrical biphasic square wave, Frequency 100 Hz, pulse duration 200 µs, current maximum intensity as tolerated for 20 minutes. During the intersurgery period, some participants began the 10-week prehabilitation program for the contralateral knee while continuing late-phase rehabilitation for the first knee. After the 2nd TKA procedure received the same postoperative rehabilitation program as in the first TKA.

Outcomes

All assessments were performed by the same physiatrist and physiotherapist at Hospital, Kediri, East Java, at the following time points: baseline (ten weeks before the second TKA, prior to initiation of the prehabilitation program) and at 3 weeks, 6 weeks, 12 weeks and 12 months after TKA. The primary outcomes were pain intensity (Visual Analogue Scale), knee range of motion (ROM), functional mobility and performance, assessed using Time Up and Go (TUG), 6 Minute walking test (6MWT), and manual resistance test (MMT) of knee extension strength. The secondary outcome was self-reported physical functions, measured using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). The 6MWT was performed only at baseline and at the 12-month follow-up. All assessments were performed in the same order for each participant, with the assessor blinded to group assignment.

1. Visual Analogue Scale (VAS): Pain intensity was assessed using the Visual Analogue Scale (VAS), a subjective pain measure rating scale on a numeric scale from o (no pain) to 10 (worst imaginable pain). Participants were instructed to quantify their pain level at the time of assessment.
2. Range of Motion (ROM): Knee joint range of motion was measured in degrees using a standard goniometer. Active knee flexion and extension were assessed with the participant in a standardised supine position. ROM measurement was used to evaluate the joint mobility and functional recovery, with a normal value of knee flexion 0-135 degrees and knee extension is) degrees.
3. Manual Muscle Test (MMT): Muscle strength of the knee extensors was assessed using Manual Muscle Testing (MMT), graded on a 0-5 scale, where indicates no visible muscle contraction and 5 indicates normal muscle strength against full resistance.
4. Time Up and Go Test (TUG): This is a simple test to measure the individual's time to get up from a straight back chair, walk to 3 meters and turn around until seated again in the same chair. Subjects are instructed to be as fast as they can do it. The same chair is used for all the assessments.
5. 6MWT: 6MWT was performed 10 weeks before TKA and 12 months after TKA. 6MWT was assessed with or without an assistive device on 18-meter indoor loops. Participants were asked to walk for 6 minutes as far as they could, and rest were permitted, but the time still counted.
6. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC): Self-reported physical function and symptoms were assessed using the WOMAC questionnaire consisting of 24 items covering pain, stiffness and physical function. Higher scores indicate worse symptoms and functional impairment. The validated Indonesian version of the WOMAC was used in this study.

Statistical Analysis

Due to the small sample size (n=7), statistical analysis was limited to descriptive methods. Data were presented at the individual participant's level to allow transparent observation of within-participant changes across assessments over time. Continuous variables were summarized using absolute values and trends rather than inferential statistics, as formal hypothesis testing would not be appropriate or sufficiently powered in this case series design. This case series is reported in accordance with the STROBE guidelines for observational studies.

RESULTS AND DISCUSSION

Table 1. Baseline Demographic.

Variable	Value
Age, years (mean +SD)	65.40 ± 4.00
Sex	Female (n=7)
Ethnicity	Indonesian Chinese, n=3 (43%) Javanese, n=4 (57%)
BMI, kg/m2 (mean +SD)	23.77 ± 4.14
Kellgren -Lawrence grade	Grade IV, n=7 (100%)
Side distribution - First TKA postoperative rehabilitation - Second TKA prehabilitation	 Right knee, n=3 (43%); Left knee, n=4 (57%) Right knee, n=4 (57%); Left knee, n=3 (43%)
Joint involvement	Mixed PFJ + TFJ, n=7 (100%)
Comorbidities	Diabetes Mellitus, n=3 (43%) Rheumatoid Arthritis, n=1 (14.29%)
Complication	Fracture, n=1(14.29%)

The study cohort comprised seven female patients (mean age 65.4 ± 4.0 years) with bilateral end-stage tricompartmental knee osteoarthritis (Kellgren-Lawrence Grade IV) and a mean BMI of 23.77 ± 4.14 kg/m², undergoing staged procedures with an average intersurgery interval of 5.86 ± 2.97 months. This demographic profile represents a consistent group of participants with severe joint degeneration but without the confounding influence of morbid obesity, ensuring that the within-patient comparisons were focused primarily on the impact of the rehabilitation protocols.

Table 2. Comparative Outcomes at 12-Month Follow-Up: 1st TKA (Control) vs. 2nd TKA (Prehabilitation).

Outcome Measure	1st TKA (Control)	2nd TKA (Prehab)
VAS Pain (0–10)	2.00 ± 0.58	1.86 ± 0.90
Knee Flexion (degrees)	110.00 ± 2.89	112.14 ± 2.67
Knee Extension Deficit (degrees)	2.86 ± 2.87	1.43 ± 2.44
MMT (0–5 scale)	3.57 ± 0.50	4.57 ± 0.53

At the 12-month primary endpoint, the prehabilitation knee (2nd TKA) demonstrated clinically superior outcomes across all primary metrics compared to the control knee (1st TKA), which received only standard postoperative care. The most significant divergence was observed in quadriceps strength, where the prehabilitation group achieved a mean MMT score of 4.57 ± 0.53 compared to 3.57 ± 0.50 in the control group, suggesting that the NMES-based intervention effectively mitigated postoperative atrophy and enhanced long-term muscular recovery.

Table 3. Longitudinal Mean Outcomes for the Prehabilitation Knee (2nd TKA).

Metric	Baseline	3 Weeks	6 Weeks	12 Weeks	12 Months
VAS Pain	8.71 ± 0.76	5.29 ± 0.76	4.14 ± 0.69	3.14 ± 0.38	1.86 ± 0.90
Knee Flexion (°)	93.57 ± 5.50	95.71 ± 3.50	103.57 ± 4.04	107.86 ± 5.27	118.57 ± 3.78
Ext. Deficit (°)	7.14 ± 2.67	9.29 ± 3.45	5.00 ± 2.89	2.14 ± 2.67	1.43 ± 2.44
MMT Strength	3.43 ± 0.79	4.14 ± 0.38	4.00 ± 0.82	4.29 ± 0.49	4.57 ± 0.53
TUG (seconds)	14.29 ± 1.03	17.00 ± 1.20	13.29 ± 0.88	13.00 ± 0.76	12.43 ± 0.90

Longitudinal analysis of the prehabilitation knee revealed a progressive recovery trajectory characterized by a steady decline in mean VAS pain scores from a severe baseline of 8.71 ± 0.76 to a functional level of 1.86 ± 0.90 at 12 months. Although a transient postoperative "dip" was observed at 3 weeks which marked by increased extension deficits (9.29°) and slower TUG performance (17.00s), all clinical and functional metrics surpassed baseline levels by the 12-week mark, ultimately resulting in a mean flexion of $118.57° and improved general mobility by the final follow-up.

Discussion

The findings of this study describe preliminary trends suggesting that the contralateral knee, which receives NMES, TENS and therapeutic exercise for 10 weeks before the TKA procedure, tends to show better functional recovery, greater quadriceps strength and lower pain intensity across 12 weeks and maintained at 12 months. These results suggest that NMES-based pre-rehabilitation may prevent the quadriceps muscle loss commonly seen after TKA. Persistent postoperative pain following TKA is often caused by peripheral nerve injury, leading to secondary neuroinflammatory processes and feeling like burning or electric shock-like pain, hypersensitivity, hypoesthesia, and accompanied by tenderness are commonly reported (Koga et al., 2024; Suresh et al., 2025). Periarticular nerve branch injury, including the infrapatellar nerve branch of the sciatic nerve, is often affected, and triggers neuroimmune interactions involving pro-inflammatory cytokines, chemokines, toll-like receptors, and activation of neuroglial cells (Tan et al., 2023). These processes have been promoting chronic pain pathways and prolonged arthrogenic muscle inhibition, contributing to delayed functional recovery.

Quadriceps muscle weakness plays a crucial role in poor outcomes after TKA surgery. Quadricep muscle is a group of four large muscles that consist of mixed fast-twitch and slow-twitch fibres that play an essential role in proprioception, knee joint stability, shock absorption and gait mechanics (Bordoni & Varacallo, 2023). Persistent quadriceps muscle weakness is strongly associated with persistent pain, impaired mobility, functional disability and poor Quality of Life (Alshahrani & Reddy, 2023; Patel et al., 2023). Sometimes it takes almost two years to restore the quadriceps muscle strength to the pre-operative level. Therefore, interventions targeting the early restoration of quadriceps activation are critical to preventing further loss of muscle strength and mass.

NMES induces muscle contraction by delivering electrical current to the motor nerve via the central nervous system bypassing the natural order (normal voluntary recruiting). Unlikely voluntary exercise, NMES recruits larger muscle fibres, fast-twitch type II fibers motor units in the early stimulation process. These fast-twitch type II fibres are more sensitive to disuse atrophy during immobilisation and surgical stress; thus, stimulation or activation during pre-rehabilitation or pre-operative may provide protective effects (Doucet et al., 2012). Because of this large and fast-twitch muscle fatigue rapidly, so a longer rest duration is required for contraction, minimal with a ratio 1:1 or better 1:5, which means 10-second contraction on, 50-second contraction off to maintain contraction quality and allows muscles to recover between stimulation (Constantin-Teodosiu & Constantin, 2021; Lievens et al., 2020). Placing the electrodes at the motor point resulted more comfortable and effective stimulation.

A previous study by Rahmati et al. also declared that short-term NMES (seven consecutive days) significantly reduced quadriceps muscle thickness loss compared to control, and five-day consecutive NMES did not increase quadriceps femoris muscle thickness but effectively prevented further muscle atrophy in Intensive Care Unit-acquired weakness (ICU-AW) (Rahmati et al., 2021). Systematic reviews have further suggested that NMES can help reduce quadriceps strength loss and muscle atrophy, consistent with our study (Li et al., 2025). Recent literature stated that NMES should be viewed as an alternative form of physical activity, not only as a rehabilitation modality, particularly for individuals with limited mobility. Ackermann et al. highlight that NMES can elicit metabolic, cardiovascular and muscular adaptations similar to those produced by voluntary exercise, including altered gene expression (Ackermann et al., 2024). This study supports the use of NMES in pre-rehabilitation for TKA patients, while traditional pre-rehabilitation programmes rely heavily on voluntary exercise, which most KOA patients cannot perform effectively. NMES provide a feasible alternative that enhances muscle capacity and recovery potential. This broader conceptual framing strengthens the novelty of our study to redefine NMES as a tool for accessible physical activity.

A similar study from a systematic review carried out by Dutta et al. stated that prerehabilitation (an exercise /physiotherapy program in the month before surgery) had minimal impact on pain and function in patients undergoing joint replacement and was not sustained over time (Dutta et al., 2024). The difference in findings between our study and theirs may be due to our longer duration (10 weeks before surgery) compared with the typical 2-4 weeks in many studies, which may have induced neuromuscular adaptation. We used NMES, which provides a different muscle activation pattern. Furthermore, most published evidence focuses on unilateral TKA or heterogeneous populations, whereas our study used a within-bilateral TKA patient, which eliminates interindividual variability and strengthens internal validity, and patients are less anxious toward the second TKA and feel more comfortable doing the pre-rehabilitation NMES.

The most significant study's limitation is a very small sample size because of the limited number of patients who had bilateral TKA and were done in a single centre, in a small city with limited population, which limited the generalizability. This study should be interpreted as a proof-of-concept pilot. The study did not include imaging or muscle ultrasound to quantify structural muscle changes. The second limitation is that our sample is exclusively Chinese Indonesian & Javanese that may not reflect the broader TKA population. The third limitation is uncontrolled interval between surgeries that range 3-12 months introducing significant heterogeneity that may affect psychological adaptation and spontaneous recovery that can confound pre-

operative rehabilitation programs. Fourth is the absence of objective muscle morphology assessment like ultrasound imaging or MRI. Finally, the NMES combines TENS and therapeutic exercise, the isolated effect of NMES cannot be fully separated.

Despite the limitation, this study provides that early NMES pre-operatively is beneficial in TKA patients, especially in populations at risk of poorer recovery, such as older adults, sarcopenia, and preoperative quadriceps weakness. Future research should include larger randomized controlled trials, standardized NMES dose and ultrasound imaging of the quadriceps muscle.

CONCLUSIONS

In this small pilot study, participants who received 10 weeks of prehabilitation before their second TKA tended to have better strength, range of motion and less pain a year later than their first TKA knee. The results of this pilot study are promising; larger controlled trials are needed to confirm the effectiveness of prehabilitation programs using NMES, TENS and therapeutic exercise and to establish standardized pre-rehabilitation protocols for TKA patients.

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Competing Interests: The authors declare that there are no competing interests.

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