Journal of Advances in Developmental Research (IJAIDR)

E-ISSN: 0976-4844 ● Website: www.ijaidr.com ● Email: editor@ijaidr.com

Neuromuscular Electrical Stimulation for Quadriceps Recovery after Total Knee Arthroplasty: Timing, Dosage and Functional Outcomes - A Narrative Review

Dr. Siva Bali Reddy Katasani[1], Dr. S Purna Chandra Shekhar[2], Dr. Amaresh Mohan[3], Dr. Sama Raju[4]

[1]Head of the Department, Seven Hills Physiotherapy & Rehabilitation, Nandyal, Andhra Pradesh, India.
ORCID: https://orcid.org/0009-0009-8282-8250
[2]Head of the Department, Chandras Homoeopathy Physiotherapy, Boduppal, Telangana, India
ORCID: https://orcid.org/0009-0008-8214-2569
[3]Associate Professor, Dept. of Physiotherapy, Health City Hospital & Institute of Paramedical Sciences, Lucknow, Uttar Pradesh, India
ORCID: https://orcid.org/0009-0000-1461-610X
[4]Research Scholar, Mahatma Gandhi University, Daramdin, Soreng, Sikkim, India.

Abstract:
Background: Quadriceps weakness after total knee arthroplasty (TKA) reflects pain, swelling, atrophy and marked failure of voluntary muscle activation. Neuromuscular electrical stimulation (NMES) can evoke contractions when voluntary recruitment is limited and may enhance early rehabilitation. Objective: To synthesize evidence published from 2012 through 2022 and translate it into a physiotherapy framework for timing, dosage, safety and progression. Methods: A structured narrative review considered English-language trials, systematic reviews and clinically relevant methodological studies published between January 2012 and December 2022. Results: Early, high-intensity NMES used as an adjunct to progressive exercise can attenuate quadriceps strength loss and improve selected functional outcomes. Treatment response depends on contraction intensity, electrode placement, pulse characteristics, session dose, adherence and integration with voluntary training. Low-intensity or brief application is less likely to provide an adequate strengthening stimulus. Skin irritation, discomfort, impaired sensation, implanted electronic devices and thrombotic or wound concerns require screening. Conclusion: NMES is most defensible for patients with substantial early activation failure and should not replace progressive resistance, mobility practice or comprehensive TKA rehabilitation.

Keywords: blood flow restriction; physiotherapy; resistance training; rehabilitation; muscle strength; hypertrophy; safety

Introduction

Total knee arthroplasty is an effective treatment for end-stage knee osteoarthritis, yet the early postoperative period is characterized by profound quadriceps weakness. Strength can decline rapidly even when surgery is uncomplicated. This weakness affects transfers, walking speed, stair negotiation, balance and confidence and may persist beyond recovery of pain and range of motion.

Loss of muscle mass contributes, but failure of voluntary activation is especially important soon after surgery. Joint swelling, pain and altered afferent input inhibit the motor-neuron pool, so the patient cannot recruit the quadriceps fully. Repeated voluntary exercise performed with poor recruitment may be insufficient to reverse the deficit.

Neuromuscular electrical stimulation applies current through surface electrodes to depolarize motor nerves and evoke a muscle contraction. It can supplement the patient's voluntary effort during a period when central drive is impaired. The approach is attractive because it targets a specific limiting mechanism rather than merely increasing the number of low-quality repetitions.

NMES outcomes depend on how it is delivered. A visible twitch is not equivalent to a strong training contraction. Electrode size and position, current amplitude, pulse duration, frequency, duty cycle, session frequency and patient tolerance influence dose. Physiotherapists therefore need a prescription framework rather than a device label.

This narrative review examines evidence from 2012 to 2022 concerning early NMES after TKA, contraction intensity, functional outcomes, adherence and safety. It emphasizes integration with ordinary rehabilitation and transition to progressive voluntary loading.

Review Aim and Method

The review aimed to determine when NMES is clinically indicated after TKA, which treatment variables influence efficacy, what outcomes may improve and how therapy should be monitored. It also considered home application, patient education and reasons for non-response.

A structured narrative search prioritized PubMed-indexed randomized trials, prospective cohorts, systematic reviews and methodological studies published in English from January 2012 through December 2022. Search terms combined total knee arthroplasty, quadriceps, neuromuscular electrical stimulation, muscle activation, strength, timing, intensity and function.

Evidence was interpreted for physiotherapy practice rather than pooled anew. Greater weight was given to controlled studies and systematic reviews. Findings from other knee procedures or healthy participants were used only for mechanism or dosage context. No original patient data were generated or analysed.

Postoperative Quadriceps Dysfunction

Quadriceps force falls sharply after TKA because voluntary activation failure and atrophy occur together. Early swelling changes joint-receptor input and can inhibit alpha motor-neuron excitability. Pain and fear further reduce effort. The result is not simple deconditioning; the patient may be unable to access existing muscular capacity.

Weakness increases the relative effort of daily tasks. Rising from a chair may require compensatory trunk flexion or greater reliance on the non-operated limb. Stair descent and balance recovery become

difficult because eccentric control is inadequate. These compensations can persist if early rehabilitation focuses only on range of motion.

Assessment should include more than manual muscle testing, which may be insensitive to large deficits. Dynamometry, standardized sit-to-stand tests, gait speed, timed up-and-go performance and stair measures provide complementary information. Observation of an extensor lag, poor quadriceps set or inability to perform a straight-leg raise suggests activation failure.

NMES is most relevant when voluntary contraction quality is low. A patient who already produces a strong quadriceps contraction and tolerates progressive resistance may gain less from the additional device. Treatment should therefore follow impairment identification rather than routine use for every arthroplasty patient.

The recovery target is functional symmetry and sufficient capacity for the person's goals, not simply a visible contraction. The programme must ultimately expose the quadriceps to progressive voluntary load and task-specific demands.

Evidence for Early NMES

The influential randomized trial by Stevens-Lapsley et al. (2012) initiated NMES very early after surgery and reported attenuation of quadriceps strength loss with improvements in functional performance. The study supported the concept that intervention should begin while activation failure is greatest rather than waiting for weakness to become established.

The relationship between contraction intensity and recovery was examined by Stevens-Lapsley et al. (2012), who found that higher NMES training intensity was associated with better quadriceps outcomes. This observation is clinically important because tolerance often limits current amplitude. A nominal programme can be ineffective if stimulation never produces a substantial contraction.

The 2021 meta-analysis by Peng et al. concluded that postoperative NMES can improve quadriceps strength across follow-up periods and may improve selected functional outcomes. Labanca et al. (2022) similarly found that studies generally favoured NMES, particularly early after TKA, while emphasizing heterogeneity and the limited effects of short-duration or low-intensity protocols.

Not every study demonstrates the same functional advantage. Differences in usual care, device settings, adherence, timing and outcome measures complicate comparison. Long-term differences may diminish once both groups progress to effective resistance training. This pattern is consistent with NMES serving as an early bridge rather than a permanent substitute.

The evidence supports selective adjunctive use, especially for marked activation failure. It does not support passive stimulation without exercise, universal application regardless of impairment or promises of accelerated recovery for every patient.

Timing of Intervention

Early initiation is biologically plausible because voluntary activation is most impaired in the first postoperative days and weeks. Delaying NMES until substantial atrophy has developed may miss the period in which it can preserve training quality. Early use should nevertheless respect wound, pain and medical status.

In hospital or immediately after discharge, the first objective is familiarization and a tolerable, visible contraction. Electrode placement can avoid the incision and dressings. The patient is positioned safely, and the therapist observes the knee, skin and systemic response.

As swelling and pain decrease, current intensity should progress. Treatment can be synchronized with a quadriceps set or terminal knee-extension task. The patient learns to contract with the stimulation rather than remaining passive. Voluntary effort may improve motor engagement and carryover.

Later in rehabilitation, NMES remains useful only if activation or strength deficits persist and voluntary loading is still inadequate. If the patient can perform progressively heavier resistance with good recruitment, time may be better spent on strength, power, balance and functional practice.

Timing also applies within a session. NMES can be used before exercise to facilitate recruitment, during isometric contractions as a strengthening dose, or after mobility work when pain is controlled. The sequence should match the limiting impairment and avoid excessive fatigue before gait or balance tasks.

Electrode Placement and Positioning

Large surface electrodes are placed over the quadriceps motor points to distribute current and recruit a broad muscle area. One common configuration positions electrodes proximally and distally over the anterior thigh. Exact placement is adjusted to obtain the strongest comfortable contraction with minimal stimulation of unwanted structures.

Skin is cleaned and inspected. Hair, lotion, poor electrode adhesion and dried reusable pads increase impedance and discomfort. Electrodes should not cross the incision or contact fragile, infected or poorly perfused skin. Placement is marked or photographed for consistent home use when consented.

The knee is commonly positioned in a supported flexed angle that allows an isometric contraction. A secure strap or fixed resistance can prevent unwanted movement and permit a stronger contraction. The patient should not be placed where sudden knee extension could cause a fall or stress healing tissue.

Position changes alter torque and comfort. A highly flexed painful knee may limit current tolerance, while complete extension can reduce the strengthening stimulus. The therapist balances joint comfort, surgical precautions and mechanical advantage.

Correct placement reduces but does not eliminate discomfort. If the patient reports sharp, focal or burning pain, skin contact and electrode condition are checked before increasing amplitude. Simply accepting poor placement and lowering intensity can undermine efficacy.

Stimulation Parameters and Contraction Dose

NMES prescription includes waveform, pulse duration, frequency, amplitude, ramp time, contraction time and rest time. Current amplitude is the most visible determinant of contraction strength, but it interacts with electrode size and pulse characteristics. Reporting only frequency is inadequate.

Frequencies that produce a fused tetanic contraction are typically selected. Pulse duration must be sufficient to recruit motor axons while remaining tolerable. A gradual ramp can reduce the surprise of contraction, though an excessively long ramp decreases time at effective force.

The duty cycle allows recovery between contractions. Strong electrically evoked contractions fatigue quickly because recruitment is relatively synchronous. A contraction period followed by a longer rest is commonly used. The number of contractions should be sufficient for training but not so large that force collapses.

Intensity should reach the maximum tolerated level that produces a strong, functional contraction within safety limits. The therapist encourages progressive increases across sessions as familiarity improves. Tolerance is not fixed; careful education and broad electrodes often permit higher amplitude.

Dose also includes sessions per day and days per week. Early trials have used frequent home sessions, but prescription must be feasible. A technically ideal protocol that the patient avoids provides no benefit. Adherence, current amplitude and completed contractions should be recorded.

The therapist reassesses the muscle response as swelling, electrode condition and sensation change. Device numbers cannot be compared directly across machines. The meaningful dose is the contraction produced and tolerated, not an arbitrary amplitude value.

Integration With Voluntary Exercise

NMES should be integrated with quadriceps sets, active knee extension and progressive resistance. The patient is instructed to contract maximally during the stimulation phase and relax during the off time. This pairing addresses both peripheral force production and voluntary motor drive.

Early voluntary exercises may include quadriceps setting, straight-leg raise when lag is controlled and supported knee extension. Closed-chain tasks such as sit-to-stand and step practice are added as weight-bearing and movement quality permit. NMES does not authorize exercises restricted by the surgical plan.

Progressive resistance remains essential. As activation improves, external load, range, sets and task difficulty increase. The programme should include hip strength, calf function, balance, gait and aerobic activity rather than becoming device centered.

Swelling and pain management support activation. Cryotherapy, compression, elevation, movement and appropriate medical management may reduce inhibitory input. NMES cannot overcome severe uncontrolled pain or a mechanical complication.

Functional carryover is tested rather than assumed. A stronger electrically evoked contraction matters only if voluntary force and activity improve. Repeated assessment determines whether NMES continues to add value.

When the patient reaches an adequate voluntary training intensity, NMES frequency can decline. Discontinuation is a planned progression, not a loss of treatment. The final goal is independent exercise and functional capacity.

Home-Based Application and Adherence

Home NMES can increase treatment frequency and reduce travel, but it transfers responsibility for electrode placement, intensity and monitoring to the patient. Suitability depends on cognition, vision, hand function, confidence and the ability to recognize warning signs.

Training begins with supervised practice. The patient demonstrates device setup, pad placement, body position, intensity adjustment, contraction timing and emergency stop. Written instructions use photographs and simple steps. Teach-back confirms understanding.

Adherence records should include sessions and achieved intensity, not only device activation. Some devices store usage, but a simple diary may be sufficient. The therapist asks about discomfort, skin response and reasons for missed sessions without blame.

Common barriers include fear of current, unpleasant sensation, complicated controls, pad cost and uncertainty about placement. Troubleshooting can improve adherence: replace worn electrodes, simplify settings, schedule sessions with a routine and explain expected sensations.

Family assistance may help when the patient consents, but the assistant must also understand safety. Home use is inappropriate when the patient cannot apply the device reliably or has a condition requiring direct monitoring.

Remote follow-up can review technique, but video may not show contraction force or skin changes accurately. Periodic in-person reassessment remains important when progress is poor or risk is elevated.

Functional Outcomes

Quadriceps strength is a primary target, but patients seek easier walking, transfers, stairs and participation. Functional tests should be chosen before intervention so that improvement can be evaluated. Timed up-and-go, sit-to-stand, walking speed and stair-climbing measures are practical.

Klika et al. (2022) reported functional improvements with NMES use after TKA, including timed up-and-go changes during follow-up. Such findings are encouraging but must be interpreted with concurrent rehabilitation and patient selection in mind.

Range of motion may improve indirectly when stronger quadriceps control supports active extension, but NMES is not a primary treatment for a fixed flexion contracture. Pain outcomes also vary. The stimulation itself may be uncomfortable even when function improves.

Patient-reported outcomes capture confidence and daily activity but can be influenced by pain, expectations and the contralateral knee. Objective and subjective measures should be considered together.

Long-term outcomes may converge between NMES and exercise groups because progressive voluntary strengthening becomes possible. The early advantage can still be clinically meaningful if it reduces disability during a vulnerable period.

Return to demanding activity requires strength, power and endurance beyond basic tests. NMES cannot replace later high-load and task-specific training. Discharge decisions should be based on goals and residual deficits rather than elapsed time.

Safety and Contraindications

NMES is generally well tolerated when screened and applied correctly. Common problems include skin redness, irritation, discomfort and delayed soreness. The skin is inspected before and after stimulation, and electrodes are replaced when adhesion deteriorates.

Implanted electronic devices, unstable cardiac conditions, impaired sensation, active thrombosis, infection and fragile skin require caution or medical guidance. Device-specific instructions and local policy should be followed. Stimulation is not applied across the chest or near areas where current could interfere with implanted systems.

Postoperative swelling is expected, but sudden calf pain, disproportionate swelling, breathlessness or chest pain requires urgent medical evaluation rather than continued stimulation. NMES should not distract from recognition of surgical complications.

Patients with reduced sensation may not detect excessive current or skin injury. Cognitive impairment may prevent safe independent use. In such cases direct supervision or another strengthening approach is preferable.

Strong contractions can stress healing tissue if position and precautions are ignored. The quadriceps contraction is isometric or performed within permitted movement. NMES does not override weight-bearing, range or wound restrictions.

The patient receives explicit stop rules: severe pain, burning, dizziness, palpitations, unusual shortness of breath or persistent skin change. Adverse responses are documented and escalated appropriately.

Patient Selection and Clinical Decision-Making

The decision begins with evidence of meaningful quadriceps activation failure or weakness. Poor quadriceps set, extensor lag, marked dynamometric deficit or inability to progress exercise supports consideration. Routine application without assessment wastes time and may reduce adherence to more important tasks.

The second question is whether the patient can tolerate and use NMES safely. Skin, sensation, medical history, implanted devices, wound status and understanding are reviewed. Barriers to home application are identified before equipment is issued.

The third question concerns dose. The clinician selects a device capable of producing an adequate contraction, places large electrodes, positions the limb securely and progresses amplitude to maximum tolerance. A low, comfortable twitch is not accepted as therapeutic simply because a session was completed.

The fourth question is whether NMES changes the rehabilitation trajectory. Strength, activation and function are reassessed after a defined period. If contraction intensity is adequate and adherence good but outcomes do not improve, the diagnosis and programme are reconsidered.

Finally, the therapist plans transition. As voluntary loading increases, NMES is reduced. Persistent weakness may require more intensive resistance, evaluation of pain and swelling, nutritional review or investigation of neurological or surgical complications.

Shared decision-making explains benefits, discomfort, alternatives and uncertainty. A patient may decline NMES and still receive effective rehabilitation. The intervention is an adjunct, not a condition of care.

A Practical Rehabilitation Pathway

During the first postoperative assessment, the therapist documents pain, swelling, wound status, range, quadriceps activation and basic function. Red flags are excluded. If activation failure is substantial, NMES familiarization begins using a safe supported position.

In the early phase, sessions emphasize strong isometric contractions synchronized with voluntary effort. Current increases gradually to maximum tolerance. The patient also performs mobility, gait, range and functional exercises. Home NMES is prescribed only after competent demonstration.

At review, the therapist checks electrode placement, stored or recorded use, current tolerance and skin. Strength and function are compared with baseline. If lag and recruitment improve, active extension and resistance progress.

In the middle phase, conventional strengthening takes priority. NMES may be retained for selected high-quality contractions or discontinued if the patient can train adequately. Sit-to-stand, step tasks and walking advance according to goals.

In the late phase, quadriceps strength, power, endurance and limb use are challenged through progressive resistance and functional loading. NMES rarely remains the main intervention. Residual asymmetry is addressed with specific exercise.

The pathway is flexible. Medical complications, severe pain or poor wound healing delay progression and require communication with the surgical team. A rapid recovery may shorten NMES use. Clinical findings, not a calendar alone, guide decisions.

Service Delivery and Documentation

Services using NMES should maintain protocols for screening, device cleaning, electrode reuse, patient instruction and escalation. Clinicians need practical competency in parameter selection and contraction assessment. A default device programme is not a substitute for training.

Documentation includes indication, skin and sensation, device, electrode position, frequency, pulse duration when available, duty cycle, amplitude or tolerance, number of contractions, voluntary effort and response. Home education and teach-back are recorded.

Audit can assess whether NMES was targeted to activation failure, whether intensity progressed, and whether strength and function were reassessed. Merely counting devices issued does not measure quality.

Cost includes equipment, electrodes and clinician time. Selective use for patients most likely to benefit may be more efficient than universal provision. Loan systems require maintenance and infection-control procedures.

Communication across hospital, home and outpatient settings prevents contradictory settings or duplicated equipment. The handover states the current dose, tolerance, goals and planned review.

Patient materials should be accessible and translated when needed. Digital videos can support learning but should not replace supervised setup. Equity requires considering whether a patient has electricity, storage, assistance and the ability to purchase replacement pads.

Managing Pain, Swelling and Fatigue

Pain and swelling influence both voluntary activation and tolerance of electrical stimulation. A patient who is guarding intensely may accept only a low current and may be unable to add voluntary effort. The first response should be to examine the cause and coordinate appropriate symptom management, not simply repeat instructions to increase intensity.

Effusion can alter quadriceps motor drive even when pain is modest. Circumference, warmth, range and symptom trajectory help distinguish expected postoperative swelling from a concerning change. Movement, elevation, compression and prescribed medical management may support recovery. Sudden or disproportionate swelling requires medical review.

Session scheduling matters. Strong NMES contractions can fatigue the quadriceps and reduce performance during gait or stair practice. When safety-critical functional training is planned, NMES may follow those tasks or use a dose that preserves performance. Alternatively, facilitation before exercise may improve recruitment in a patient whose main limitation is activation.

The next-day response is reviewed. Mild muscle soreness can be expected after an adequate strengthening dose, but severe pain, increased joint irritability or reduced function suggests excessive dose or another problem. Current amplitude, contraction number, voluntary exercise and total daily activity are considered together.

Analgesic timing may improve tolerance, but the therapist should not use reduced sensation to deliver excessive current. The patient must remain able to report discomfort and skin symptoms. Cryotherapy immediately before electrode placement can alter sensation and should be considered when setting intensity.

Fatigue is not a reason to avoid strengthening indefinitely. The programme may use fewer high-quality contractions with adequate rest rather than many weak contractions. Quality of evoked force and recovery is more important than completing a predetermined duration.

Reasons for Limited Response

A weak response to NMES often reflects modifiable delivery problems. Small or poorly placed electrodes concentrate current and cause discomfort before the quadriceps contracts strongly. Worn pads, dry skin contact, excessive adipose tissue and an unsuitable waveform may also reduce tolerability or force.

Dose failure is common when amplitude remains at the first comfortable setting across weeks. Patients may assume that visible movement is sufficient and avoid progression. Supervised review can demonstrate the relationship between contraction strength and training goal while respecting individual tolerance.

Adherence failure may be hidden when a patient reports using the device but completes few contractions or shortens sessions. Nonjudgmental discussion identifies fear, inconvenience, pad cost, complicated controls or uncertainty about the incision. The plan should be simplified when possible.

Biological and mechanical factors also matter. Persistent severe swelling, nerve injury, extensor-mechanism problems, infection, anaemia, poor nutrition or uncontrolled pain can limit recovery. NMES should not delay investigation. A plateau despite adequate delivery and exercise prompts reassessment and communication with the surgical team.

Outcome mismatch can create a false impression of failure. NMES may improve quadriceps strength without changing pain dominated by another structure. Conversely, walking may improve through compensation while the operated quadriceps remains weak. Measures should correspond to the treatment target.

Finally, expectations may be unrealistic. NMES does not reverse years of preoperative weakness within days. Recovery depends on repeated exposure, voluntary training and overall health. Clear goals and review dates allow the clinician and patient to decide whether continued use is justified.

Preoperative Education and Continuity of Care

Preoperative education can introduce the reason for postoperative quadriceps weakness and explain the possible role of NMES. Familiarity reduces anxiety when treatment begins soon after surgery. It also allows screening for skin problems, implanted devices and practical barriers before discharge.

Routine preoperative NMES for every patient is not established as necessary. The value of the preoperative period may lie more in baseline measurement, device practice and strengthening than in

electrical stimulation itself. Patients with marked preoperative weakness may require a broader prehabilitation programme.

Baseline quadriceps strength and functional tests help interpret postoperative change. The therapist documents the contralateral limb, use of walking aids, stair demands and home support. These details shape outcome targets and home-device suitability.

Continuity between inpatient, home and outpatient teams is essential. The handover states electrode placement, device settings, tolerated amplitude, session schedule, skin response and progress. A new clinician should verify these findings rather than copying settings without examination.

Patients need one consistent message: NMES is an adjunct to active recovery. Conflicting advice about whether to contract voluntarily, how high to set the current or when to stop undermines confidence. Written instructions should match verbal teaching.

When a device is loaned, responsibility for return, cleaning, replacement electrodes and technical support is defined. Equipment failure should not interrupt all strengthening; the patient retains a voluntary exercise plan. This protects rehabilitation from becoming dependent on technology availability.

Illustrative Clinical Application

Consider an older adult five days after uncomplicated unilateral TKA who demonstrates marked quadriceps inhibition, an extensor lag and difficulty rising from a chair. The wound is protected, sensation is intact and medical screening reveals no contraindication. The therapist explains NMES, places broad electrodes over the quadriceps and positions the knee securely for an isometric contraction.

The first session establishes a visible, tolerable contraction synchronized with a voluntary quadriceps set. Current increases across contractions while skin, pain and systemic response are monitored. The patient then practises transfers, walking and range exercises. Because activation failure is substantial and the patient demonstrates safe device use, a structured home programme is considered.

At the next review, the therapist inspects the skin, confirms placement and checks the recorded sessions. The patient has kept amplitude low because the sensation felt unfamiliar. Supervised coaching and replacement of a poorly adhering electrode produce a stronger, more tolerable contraction. The written plan is updated with a gradual intensity target and clear stop rules.

Two weeks later, extensor lag has reduced and sit-to-stand performance has improved, but dynamometry still shows a large deficit. NMES continues while knee-extension and closed-chain resistance progress. Swelling response and next-day function remain acceptable.

By six weeks, the patient can perform progressive voluntary resistance at a meaningful load and climbs stairs with improved control. NMES frequency is reduced, then discontinued. The programme advances to heavier quadriceps strengthening, balance, walking endurance and goal-specific tasks.

This example is not a universal protocol. It demonstrates the reasoning sequence: identify activation failure, exclude contraindications, achieve an adequate contraction, integrate active exercise, measure response and withdraw NMES when voluntary loading becomes sufficient. If wound problems, sudden swelling, neurological symptoms or persistent non-response had emerged, the pathway would have shifted toward medical review rather than greater current.

Clinical Handover Standard

A safe handover records the indication for NMES, wound and skin status, electrode map, patient position, pulse settings, duty cycle, achieved amplitude, number of contractions, voluntary effort and adverse symptoms. It also identifies the next progression criterion and the circumstances requiring cessation or medical contact. This level of detail prevents a receiving clinician from relying on a vague statement that electrical stimulation was used. Settings should still be reassessed because swelling, sensation, electrode condition and tolerance change during recovery.

Practice Note

Final decisions should always reflect current surgical precautions, patient goals, clinical response and informed preference.

Limitations and Research Priorities

Evidence is limited by heterogeneous NMES parameters, small trials, varied usual care and inconsistent outcomes. Some studies do not report achieved contraction intensity, making an apparently negative protocol difficult to interpret. Blinding is challenging.

Future trials should standardize reporting of electrode size, waveform, pulse duration, frequency, duty cycle, amplitude, evoked torque, adherence and co-interventions. Dose-response research should identify minimum effective and tolerable contraction intensity.

Studies should stratify by baseline activation failure because patients with mild deficits may dilute benefit for those with severe inhibition. Pragmatic trials should include home adherence, cost and implementation outcomes.

Longer follow-up is needed to determine whether early strength preservation changes falls, activity, satisfaction or long-term participation. Research should include diverse ages, comorbidities and health systems.

Comparisons with modern high-quality rehabilitation are essential. NMES should demonstrate added value beyond progressive strengthening, swelling management and functional training, not only beyond minimal care.

Until stronger evidence is available, clinicians should individualize use and avoid claiming that one parameter set is universally optimal.

Conclusion

Quadriceps weakness after TKA is driven strongly by early voluntary activation failure as well as atrophy. NMES can evoke a training contraction during this period and, when initiated early at a high tolerated intensity, may attenuate strength loss and improve selected functional outcomes.

Efficacy depends on electrode placement, adequate current, duty cycle, session frequency, adherence and integration with voluntary exercise. Low-intensity stimulation that produces only a twitch is unlikely to substitute for a strengthening contraction.

NMES should be targeted to patients with meaningful activation deficits, screened for safety and reassessed against strength and functional goals. It does not replace progressive resistance, gait, balance, mobility or task practice.

The most defensible model uses NMES as an early bridge: facilitate quadriceps recruitment, support active exercise and withdraw the device as voluntary loading becomes effective. This function-oriented approach keeps technology subordinate to recovery.

REFERENCES:

1. Klika, A. K., Yakubek, G., Piuzzi, N. S., Calabrese, G., Barsoum, W. K., & Higuera, C. A. (2022). Neuromuscular electrical stimulation use after total knee arthroplasty improves early return to function. Journal of Knee Surgery, 35(1), 104-111.
2. Labanca, L., Bonsanto, F., Raffa, D., Orlandi Magli, A., & Benedetti, M. G. (2022). Does adding neuromuscular electrical stimulation to rehabilitation following total knee arthroplasty lead to a better quadriceps muscle strength recovery? A systematic review. International Journal of Rehabilitation Research, 45(2), 118-125. https://doi.org/10.1097/MRR.0000000000000525
3. Peng, L., Wang, K., Zeng, Y., Wu, Y., Si, H., & Shen, B. (2021). Effect of neuromuscular electrical stimulation after total knee arthroplasty: A systematic review and meta-analysis of randomized controlled trials. Frontiers in Medicine, 8, 779019. https://doi.org/10.3389/fmed.2021.779019
4. Stevens-Lapsley, J. E., Balter, J. E., Wolfe, P., Eckhoff, D. G., & Kohrt, W. M. (2012). Early neuromuscular electrical stimulation to improve quadriceps muscle strength after total knee arthroplasty: A randomized controlled trial. Physical Therapy, 92(2), 210-226. https://doi.org/10.2522/ptj.20110124
5. Stevens-Lapsley, J. E., Balter, J. E., Wolfe, P., Eckhoff, D. G., Schwartz, R. S., Schenkman, M., & Kohrt, W. M. (2012). Relationship between intensity of quadriceps muscle neuromuscular electrical stimulation and strength recovery after total knee arthroplasty. Physical Therapy, 92(9), 1187-1196. https://doi.org/10.2522/ptj.20110479
6. Thomas, A. C., Stevens-Lapsley, J. E., & Mizner, R. L. (2012). Importance of attenuating quadriceps activation deficits after total knee arthroplasty. Exercise and Sport Sciences Reviews, 40(2), 95-101. https://doi.org/10.1097/JES.0b013e31824a732b