Restoration of physical function in patients following total knee arthroplasty: an update on rehabilitation practices

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Purpose of review
Previous studies on rehabilitation following total knee arthroplasty (TKA) demonstrated limited efficacy in increasing long-term outcomes. More recently, several rehabilitation approaches have demonstrated greater efficacy for increasing long-term strength and functional performance outcomes following TKA.

Recent findings
Neuromuscular electrical stimulation (NMES), applied to the surgical limb’s quadriceps muscle for the first 6 weeks following surgery, has been shown to improve the speed of recovery from TKA and leads to long-term increases in strength and functional performance. Rehabilitation programs that incorporate higher intensity, progressive resistive exercises that target all major muscle groups of the lower extremity have demonstrated superior long-term strength and functional gains compared with lower intensity programs. Finally, although the greatest strength and functional losses occur immediately after surgery, there is emerging evidence that strength and functional gains can be made after the acute postoperative recovery period with programs focusing on the use of progressive aquatic exercise or eccentric exercise.

Summary
Functional recovery following TKA can be enhanced by the use of NMES and utilization of a comprehensive, higher intensity strength training program in conjunction with traditional rehabilitation approaches.

Keywords
outcomes, rehabilitation, total knee arthroplasty

INTRODUCTION
Total knee arthroplasty (TKA) is the most commonly performed musculoskeletal surgery in the United States with over 687,000 TKAs performed annually [1,2].

End-stage knee osteoarthritis is the primary disease condition that leads to TKA and accounts for 72.7% of TKAs performed in the United States [3]. Although TKA reliably reduces the joint pain associated with knee osteoarthritis, strength and function are rarely restored to the level of healthy adults [4–8]. Long-term limitations in strength and function occur because individuals with end-stage knee osteoarthritis demonstrate significant limitations in strength and function preoperatively [4,9], which are then magnified by strength and functional losses that occur secondary to surgery itself [4,10–12]. Prior to surgery, individuals with end-stage knee osteoarthritis demonstrate 36% lower quadriceps strength, 160% longer stair climbing test (SCT) times, and walk 31% less distance on the 6-min walk (6MW) test compared with healthy adults without knee pain [4]. In the first month following surgery, quadriceps strength further decreases by up to 60% compared with preoperative levels [4,10]. Function also decreases dramatically in the first month, with performance on the SCT decreasing by 90% and walking distance on the 6MW test decreasing by 40% [4]. Six months after surgery, patients still exhibit significant strength and functional deficits compared with their healthy peers. Compared with healthy adults, individuals after
KEY POINTS

- Neuromuscular electrical stimulation (NMES), applied to the surgical limb’s quadriceps muscles, should be utilized twice daily, beginning on postoperative day 2.
- Strategies to increase patient comfort with NMES should be utilized, as achieving maximal stimulation of the quadriceps is vital for optimal outcomes.
- Rehabilitation programs should target all major muscle groups of the lower extremity and utilize progressive resistive exercise training principles.

TKA have 40% lower quadriceps strength, walk 30% less distance on the 6MW test, and take 110% longer on the SCT [4]. Combined, these strength and functional deficits predispose individuals to increasing disability with age as well as an increased risk of falling and loss of functional independence [13,14]. Despite these known long-term deficits in strength and function following TKA, evidence on optimal rehabilitation practices following TKA have been slow to emerge. In 2002, the National Institutes of Health consensus statement on TKA concluded that ‘the use of rehabilitation services is perhaps the most understudied aspect of the peroperative management of TKA patients.... [and] there is no evidence supporting the generalized use of any specific preoperative or postoperative rehabilitation intervention’ [15]. In 2008, a meta-analysis by Minns Lowe et al. [16] identified a total of 27 studies on rehabilitation following TKA of which only five studies met the inclusion criteria for the meta-analysis. This meta-analysis concluded that physical therapy resulted in ‘no long term benefit’ based upon current evidence. However, since this meta-analysis, there have been several new rehabilitation approaches that have demonstrated superior long-term outcomes following TKA compared with more traditional approaches. Neuromuscular electrical stimulation (NMES) to the quadriceps musculature and a comprehensive, higher intensity, progressive resistive exercise program have both been utilized successfully in the early postoperative period and have demonstrated long-term increases in strength and function. Additionally, progressive aquatic exercise and eccentric strengthening have been utilized after the acute postoperative period and have also demonstrated initial success for increasing strength and function.

QUADRICEPS NEUROMUSCULAR ELECTRICAL STIMULATION

The long-term quadriceps strength deficits observed in individuals after TKA have profound implications for the older adult, as decreased quadriceps strength has been associated with decreased stair climbing ability, decreased gait speed, aberrant movement patterns, an increased risk of falling, and loss of functional independence [10,13,14,17,18]. Therefore, remediation of quadriceps strength deficits should be a primary goal of any rehabilitation program.

Several recent studies have examined the use of neuromuscular stimulation to the quadriceps following TKA to address quadriceps weakness. Petterson et al. [19] examined the use of NMES applied to the quadriceps muscle on the surgical limb for 6 weeks beginning 4 weeks after TKA, utilizing a randomized, single-blind study design. Patients randomized to the NMES group followed a progressive exercise program (discussed in the following section) in addition to receiving NMES two to three times per week as a component of their outpatient physical therapy treatment. The NMES stimulator was set to 50Hz, a pulse duration of 400 μs, and a 10 s on-time followed by a 80 s rest-time for a total of 10 contractions with the current intensity set at the patient’s maximum tolerance. Compared to the control group, which only followed the progressive exercise program, the NMES group had similar outcomes in terms of quadriceps strength, quadriceps activation, 6MW distance, SCT time, and Timed Up and Go (TUG) time at 12 and 52 weeks. It is worth noting that both groups experienced significantly greater strength and functional performance improvements compared with a cohort of individuals who received a lower intensity rehabilitation program. The lack of improvements with NMES treatment in this trial may have resulted from waiting to initiate NMES until 4 weeks after TKA when initial activation and strength deficits may have started to resolve. Furthermore, NMES application was limited to 10 contractions, two to three times per week, which may not have been enough of a stimulus to induce changes in quadriceps muscle function.

As the greatest loss of quadriceps strength occurs in the first month following TKA, Avramidis et al. [20] examined the use of NMES to the quadriceps muscle on the surgical limb for 6 weeks beginning on postoperative day 2, utilizing a randomized, single-blind study design. Patients randomized to the NMES group followed a traditional physical therapy program, in addition to using a NMES stimulator twice a day for 2 h while lying in bed or sitting. The NMES stimulator was set to 40Hz, a pulse duration of 300 μs, and an 8 s on-time followed by a 8 s rest-time with the current intensity set at the patient’s maximum tolerance. Compared with the control group, which received traditional physical therapy alone, the NMES group demonstrated faster walking speeds.
and better scores on the Oxford Knee Score and Knee Society function score at 6 and 12 weeks following TKA, although differences between groups were no longer significant at 52 weeks. The NMES group had significantly better Short Form-36 physical component scores at 6, 12, and 52 weeks postoperatively compared with the control group. No complications were associated with use of NMES beginning on postoperative day 2, although three of 35 patients abandoned use of the stimulator secondary to discomfort. Although NMES treatment starting acutely after TKA was beneficial, the question of whether 4 h of NMES application per day was necessary remained unknown.

Similarly to the study by Avramidis et al. [20*], Stevens-Lapsley et al. [21**] examined the use of NMES to the quadriceps muscle early after TKA using only 30 min of total treatment per day utilizing a randomized, unblinded study design. Treatment began on postoperative day 2 and continued for 6 weeks, in addition to a standardized rehabilitation program. Patients utilized NMES for 15 isometric contractions twice daily (30 min total treatment per day) (Fig. 1) [21**]. The NMES stimulator was set at 50 Hz, a pulse duration of 250 μs, and a 15 s on-phase followed by a 45 s rest-time with the current intensity set at the patient’s maximum tolerance. Compared with the control group, which received the standardized rehabilitation program alone, the NMES group demonstrated superior quadriceps strength, hamstring strength, 6MW distances, TUG times, SCT times, and active knee extension at 3.5 weeks after TKA (Fig. 2) [21**]. At 52 weeks, significant differences between groups were still observed, with the NMES group demonstrating superior quadriceps strength, hamstring strength, and functional performance on all measures compared with the control group. Similarly to the study by Avramidis et al. [20*], no adverse events were observed with the utilization of NMES beginning on postoperative day 2.

A key observation from the Stevens-Lapsley et al. [22] trial was that patients who were capable of achieving higher stimulator intensity had greater strength and functional gains compared with those utilizing a lower intensity. Therefore, increasing the comfort of NMES to accomplish this goal is vital. Avramidis et al. [20*] utilized 70 ± 70 mm electrodes, a shorter rest-time, and had 10% of patients discontinue use of the stimulator as well as only short-term benefits in terms of function. Stevens-Lapsley et al. [21**] utilized larger 76 ± 127 mm electrodes (Supertrodes, SME Inc., Wilmington, USA), as well as longer rest-times (45 vs. 8 s) and shorter NMES treatment times (15 min compared with 2 h) per session. These differences may have enabled patients to achieve higher stimulation intensities and, thus, greater strength gains, which may explain why the trial by Stevens-Lapsley et al. [21**] observed long-term benefits in addition to short-term benefits.

**HIGH INTENSITY PROGRESSIVE RESISTIVE EXERCISE**

Although NMES shows promise for increasing recovery rates and achieving higher long-term strength and function performance, some individuals are unable to utilize NMES secondary to discomfort or contraindications to NMES use (e.g., cardiac pacemakers, cardiac arrhythmia, venous or arterial thrombosis or thrombophlebitis, or malignancy near area of application). Moreover, recent evidence has emerged that strength loss following TKA occurs not only in the knee extensors but also in the knee flexors and ankle plantar flexors [11,23]. Furthermore, hip abductor strength has been shown to be a significant predictor of functional performance following TKA [24]. Therefore, rehabilitation programs need to effectively target all major muscle groups of the lower extremity to achieve maximal results.

In addition to rehabilitation programs needing to be comprehensive in terms of muscle groups trained, the intensity at which exercise is performed is a key variable in realizing maximal strength and
Rehabilitation medicine in rheumatic diseases

FIGURE 2. Changes in functional performance over time (mean ± SD) in neuromuscular electrical stimulation (NMES) and control groups. (a) Stair climbing test. (b) Six-minute walk test. (c) Timed Up and Go test. Significant differences between groups are indicated by the asterisk (*P < 0.05). Reprinted from [21**].

functional performance gains. Traditional rehabilitation programs, such as those described in the meta-analysis by Minns Lowe et al. [16], utilize very low-intensity strengthening exercises that are typically limited to active range of motion, isometric contractions, or resistive exercise utilizing ankle weights or resistive bands. The lack of efficacy of low-intensity rehabilitation programs could potentially be related to not achieving a high enough intensity to realize optimal gains in muscular strength and function.

There is preliminary evidence that a higher intensity, comprehensive, progressive resistive exercise program can be successfully utilized following TKA. Petterson et al. [19**] initiated this type of program 3–4 weeks after TKA. Patients attended therapy sessions two to three times per week for 6 weeks and performed two to three sets of 10 repetitions of resistive exercises targeting the knee extensors, knee flexors, hip extensors, and ankle plantar flexors based on a 10 repetition maximum. In order to achieve maximum gains, strength training machines were utilized once ankle weights and resistive bands did not produce fatigue. Their program also included traditional physical therapy interventions targeting function and range of motion, but the resistive training program was the novel part of their intervention. They demonstrated that, compared with patients who received physical therapy treatment in the community typically without higher intensity strength training, their program resulted in superior quadriceps strength, 6MW distances, TUG times, and SCT times 52 weeks after surgery. A key limitation of this study was that the intervention was initiated 3–4 weeks after TKA when the largest strength and functional losses had already occurred.

An unblinded, prospective cohort study by Bade and Stevens-Lapsley [25**] with an age-matched and sex-matched control group demonstrated preliminary efficacy in utilizing a higher intensity, comprehensive, progressive resistive exercise program combined with a program that also incorporates balance, agility, endurance, and functional exercises initiated following hospital discharge. Patients participated in therapy sessions two to three times per week for 12 weeks and performed two sets of 10 repetitions of progressive resistive exercises targeting the hip abductors, hip adductors, hip flexors, hip extensors, knee flexors, knee extensors, and ankle plantar flexors based on the patient’s 10-RM. Patients were advanced through a four-phase rehabilitation program utilizing predetermined milestones (Table 1) [25**]. Patients in the higher intensity program demonstrated superior quadriceps strength, TUG times, and SCT times at 3.5 and 12 weeks after
<table>
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<th>Table 1. High intensity rehabilitation program</th>
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<td><strong>Phase I (week 0–2)</strong></td>
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<td>Supine knee flexion (heel slides)</td>
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<td>Short arc knee extensions</td>
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<td>Standing bilateral squats</td>
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<td>Side lying hip external rotation with hips flexed to 45° and knees flexed to 90°&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>Side lying hip adduction</td>
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<td>Supine ankle plantar flexion and dorsiflexion (ankle pumps)</td>
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<td>Progression: when able to complete 2 × 8 repetitions without fatigue, NPRS at rest &lt; 5/10, ROM &gt; 15–80°</td>
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<td>Marching or single limb stance</td>
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<td>Multidirectional stepping</td>
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<td>Progression: when able to complete 2 × 8 reps without fatigue, NPRS at rest &lt; 5/10, ROM &gt; 15–90°</td>
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<tr>
<td>Stability ball supine hip extension</td>
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<td>Progression: when able to complete 2 × 8 repetitions without fatigue, NPRS at rest &lt; 3/10, ROM &gt; 10–100°</td>
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<sup>a</sup>This program was utilized in conjunction with a traditional rehabilitation program that included functional training, endurance exercises, ROM exercises, and manual therapy techniques. NPRS, numeric pain rating scale; ROM, active knee range of motion. Reprinted from [25**].

<sup>a</sup>Resistive exercise utilizing ankle weight, resistive band, cable column, or machine.
TKA compared with the control group that completed a standardized lower intensity program. At 52 weeks, patients in the higher intensity program demonstrated superior SCT times and 6MW distances. Importantly, patients in the higher intensity program at 52 weeks demonstrated functional performance scores on the 6MW, TUG, and SCT equivalent to healthy adults without knee pain, suggesting that this program has the potential to restore function to normative levels.

Although there is concern that a higher intensity rehabilitation program may lead to increased postoperative pain levels, increased swelling, decreased knee range of motion, and increased risk of injury, none of these adverse effects was observed in either of the aforementioned studies.

**LATE-PHASE REHABILITATION PROGRAMS**

The greatest declines in strength and functional performance occur in the immediate postoperative period; therefore, this period should be a primary target of rehabilitation, as preventing functional loss in the short term is likely to be more effective than working to reverse losses months after surgery. However, two recent studies have examined the effectiveness of a late-phase supervised rehabilitation program once formal rehabilitation has ended. Valtosen et al. [26] utilized a progressive aquatic resistance training class for individuals 4–12 months after TKA, twice a week for 12 weeks utilizing a randomized, predominantly unblinded study design. The investigators found that the class participants had superior quadriceps strength, habitual walking speed, and stair ascending time compared with a control group, which received no intervention. LaStayo et al. [27] compared a traditional progressive resistance exercise program with an eccentric resistance training program utilizing the Eccentric (BTE Technologies, Hanover, USA) in individuals 1–4 years after TKA, utilizing a randomized, predominantly unblinded study design. Both groups trained for 30 min, three times per week for 12 weeks. Both groups demonstrated increased performance on the TUG and stair ascent at the end of training. In addition to these positive effects, the eccentric group also demonstrated additional gains in quadriceps strength, quadriceps volume, 6MW distance, and stair descent time that were not observed in the traditional group.

**CONCLUSION**

Rehabilitation protocols for patients following TKA should incorporate the utilization of NMES and comprehensive, higher intensity, progressive resistive exercises targeting the major muscle groups of lower extremity. For patients that have not achieved optimal outcomes following the completion of this rehabilitation program, use of progressive aquatic exercise or eccentric strengthening may provide additional benefit.

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**Conflicts of interest**

The authors of this article have no conflicts of interest to report.

**REFERENCES AND RECOMMENDED READING**

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 000–000).


This study demonstrated that a progressive rehabilitation intervention, initiated 1 month after TKA, leads to superior long-term outcomes compared with a lower intensity intervention. Additionally, this study demonstrated that NMES use, two to three times per week, initiated 1 month after TKA, did not improve outcomes.


This study demonstrated that NMES use, 4 h daily for 6 weeks, initiated on postoperative day 2, improved short-term outcomes.


This study demonstrated that NMES use, 30 min daily for 6 weeks, initiated on postoperative day 2, improved both short-term and long-term outcomes.


This study demonstrated that utilization of a progressive rehabilitation intervention, initiated upon hospital discharge, leads to superior short-term and long-term outcomes compared with a lower intensity, shorter duration rehabilitation program.


This study demonstrated that use of an aquatic resistive training program could improve strength and function in patients 4–12 months after TKA.


This study demonstrated that eccentric strengthening produced superior strength and functional gains compared with traditional progressive exercise in patients 1–4 years after TKA.