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Original Article

The Role of Neuromuscular Electrical Stimulation in Improving Muscle Strength in Spinal Cord Injury Patients

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ABSTRACT

Background: Spinal cord injury is associated with lower-limb weakness, disuse-related muscle wasting, reduced functional independence, and prolonged rehabilitation needs. Neuromuscular electrical stimulation may help activate weak or poorly recruited muscles and support strength recovery when combined with conventional rehabilitation. Objective: To evaluate the effect of adjunctive neuromuscular electrical stimulation on quadriceps strength, muscle bulk, spasticity, and functional independence in patients with spinal cord injury. Methods: This parallel-group controlled experimental study was conducted in a tertiary care rehabilitation department in Islamabad, Pakistan. Forty patients with spinal cord injury were allocated equally to conventional physiotherapy alone or conventional physiotherapy plus NMES for 12 weeks. NMES was applied bilaterally to the quadriceps for 20 minutes per session, five days per week. Outcomes included handheld dynamometry-based quadriceps strength, thigh circumference, ultrasonographic mid-thigh cross-sectional area, Modified Ashworth Scale score, SCIM-III score, adherence, and adverse events. Results: Four participants did not complete the intervention. Quadriceps strength increased from 11.6 ± 3.0 kg to 22.8 ± 4.8 kg in the NMES group and from 11.4 ± 3.1 kg to 14.0 ± 3.9 kg in the conventional physiotherapy group. SCIM-III improved from 37.8 ± 7.9 to 52.3 ± 9.1 with NMES and from 38.2 ± 8.4 to 44.1 ± 8.9 with conventional physiotherapy. Greater numerical improvements were also observed in thigh circumference and mid-thigh cross-sectional area with NMES. Conclusion: Adjunctive NMES was associated with greater improvement in quadriceps strength, muscle bulk, and functional independence over 12 weeks, with minor adverse events. Larger controlled trials with robust inferential analysis are required. Keywords: neuromuscular electrical stimulation; spinal cord injury; quadriceps strength; rehabilitation; functional independence; SCIM-III; muscle bulk

INTRODUCTION

Spinal cord injury is a disabling neurological condition that produces substantial motor, sensory, autonomic, and functional limitations. Beyond the primary neurological insult, patients commonly develop rapid secondary musculoskeletal deterioration, particularly in the muscles below the neurological level of injury. Reduced voluntary activation, prolonged immobility, altered muscle loading, and impaired neural input contribute to progressive muscle weakness, reduction in cross-sectional area, increased fatigability, and changes in body composition. These impairments restrict participation in essential rehabilitation tasks such as bed mobility, supported standing, transfer training,

gait-related practice, wheelchair mobility, and self-care, thereby increasing long-term dependency and rehabilitation burden (1).

Loss of lower-limb muscle strength is especially important in patients with spinal cord injury because it affects both structural preservation and functional recovery. Quadriceps weakness limits knee control during supported standing and transfer-related activities, while disuse atrophy reduces the mechanical and metabolic reserve required for sustained rehabilitation participation. Previous literature has shown that muscle cross-sectional area can decline substantially in the early months after spinal cord injury, particularly when lower-limb muscles are not exposed to sufficient contractile loading. Therefore, interventions capable of activating weak or partially paralyzed muscles may help preserve muscle tissue, support progressive rehabilitation, and improve functional outcomes when integrated into a structured rehabilitation program (2).

Neuromuscular electrical stimulation is a rehabilitation technique in which surface electrodes deliver electrical impulses to peripheral nerves or muscles to evoke visible muscle contractions. In spinal cord injury rehabilitation, NMES is clinically valuable because it can activate muscles that patients may be unable to recruit adequately through voluntary effort alone. Repeated electrically evoked contractions may improve local muscle loading, enhance circulation, reduce disuse-related wasting, and provide a strengthening stimulus that complements conventional physiotherapy. Although functional electrical stimulation is often used during task-oriented activities such as cycling, stepping, or grasping, NMES may also be applied as a focused strengthening intervention for selected muscle groups, including the quadriceps (3,4).

Evidence from previous studies and reviews suggests that electrical stimulation-based rehabilitation may improve muscle size, voluntary strength, metabolic health, aerobic capacity, and selected functional outcomes in individuals with spinal cord injury. However, reported effects vary across studies because of differences in injury level, completeness of injury, chronicity, stimulation parameters, treatment duration, intensity of contraction, and integration with conventional rehabilitation. The literature also indicates that NMES is most clinically meaningful when it is not used as an isolated machine-based modality but is incorporated into goal-directed rehabilitation, where gains in muscle performance can support standing, transfers, gait-related training, and functional independence (5–9).

Despite the growing international evidence base, local data from Pakistan remain limited. This gap is important because patients with spinal cord injury in Pakistan often face delayed rehabilitation, transport difficulty, financial constraints, variable access to specialized services, and limited availability of advanced rehabilitation technologies. NMES is relatively simple, non-invasive, repeatable, and potentially adaptable to routine inpatient or outpatient physiotherapy settings. For tertiary rehabilitation units, particularly in resource-constrained settings, it is therefore important to evaluate whether adding NMES to conventional physiotherapy produces clinically meaningful improvement in strength, muscle bulk, spasticity, and functional independence.

The present study was designed to evaluate the effect of adjunctive NMES on quadriceps muscle strength in patients with spinal cord injury receiving conventional rehabilitation at a tertiary care hospital in Islamabad, Pakistan. The study also examined changes in thigh circumference, ultrasonographic mid-thigh muscle cross-sectional area, spasticity, functional independence, adherence, and adverse events over a 12-week intervention period. It was hypothesized that patients receiving NMES in addition to conventional physiotherapy would demonstrate greater improvement in quadriceps strength and functional independence than patients receiving conventional physiotherapy alone.

MATERIALS AND METHODS

This parallel-group controlled experimental study was conducted in the Department of Physical Medicine and Rehabilitation of a tertiary care hospital in Islamabad, Pakistan, from January to

September 2025. The study evaluated the comparative effect of conventional physiotherapy alone and conventional physiotherapy combined with neuromuscular electrical stimulation in patients with spinal cord injury. The intervention period was 12 weeks, with repeated outcome assessment at baseline, week 4, week 8, and week 12. The primary outcome was quadriceps muscle strength measured by handheld dynamometry, while secondary outcomes included thigh circumference, ultrasonographic mid-thigh muscle cross-sectional area, lower-limb spasticity, functional independence, treatment adherence, and adverse events.

Patients with traumatic or non-traumatic spinal cord injury were enrolled through consecutive sampling from the rehabilitation department. Eligible participants were adults aged 18–60 years with injury duration between 1 and 9 months, medically stable status, lower-limb weakness attributable to spinal cord injury, and ability to participate in supervised rehabilitation sessions. Patients were excluded if they had open skin lesions at electrode placement sites, pacemakers or implanted electrical devices, uncontrolled autonomic dysreflexia, unstable fractures, severe fixed contractures, lower motor neuron denervation of the target quadriceps muscle, or severe cognitive impairment preventing safe participation or reliable assessment. Written informed consent was obtained from all participants or their legal attendants before enrollment.

A total of 40 participants were allocated in a 1:1 ratio into two groups. The control group received conventional physiotherapy, while the intervention group received the same conventional physiotherapy program with additional NMES applied to both quadriceps muscles. Because the available study information does not specify a random sequence generation or allocation concealment process, the design was reported as a controlled experimental study rather than a randomized controlled trial. To reduce performance and measurement bias, both groups received physiotherapy according to a consistent departmental protocol, outcome assessments were performed at predefined timepoints, and the same measurement procedures were followed across participants. Where feasible, post-intervention assessments were performed by an assessor not involved in delivering the intervention.

Participants in the control group received conventional physiotherapy five days per week for 12 weeks. The program included passive and active-assisted range-of-motion exercises, bed mobility training, sitting balance training, transfer training, supported standing using a standing frame when indicated, strengthening of available upper- and lower-limb muscles, and gait-related training for participants with incomplete injuries who were clinically suitable for such training. Treatment progression was based on medical stability, tolerance, voluntary motor capacity, balance control, and functional performance during supervised sessions.

Participants in the intervention group received the same conventional physiotherapy program plus NMES to both quadriceps muscles. NMES was delivered using surface electrodes placed over the quadriceps motor points to elicit visible and tolerable tetanic contractions. Each NMES session lasted 20 minutes and was delivered five days per week for 12 weeks. A symmetrical biphasic current was used with a pulse duration of 300 microseconds, frequency of 35 Hz, and an on:off cycle of 10 seconds of stimulation followed by 20 seconds of rest. Stimulation intensity was gradually increased until a clear quadriceps contraction was observed within patient tolerance. Skin condition, discomfort, autonomic symptoms, and treatment tolerance were monitored during sessions, and electrode position or current intensity was adjusted when required.

Quadriceps muscle strength was measured in kilograms using handheld dynamometry and treated as the primary outcome. Measurements were obtained at baseline, week 4, week 8, and week 12 using the same testing approach across timepoints. Thigh circumference was used as a simple clinical indicator of muscle bulk and was measured at the mid-thigh region using a measuring tape. Ultrasonographic mid-thigh muscle cross-sectional area was recorded as an imaging-based estimate of local muscle morphology. Lower-limb spasticity was assessed using the Modified Ashworth Scale, and functional independence was assessed using the Spinal Cord Independence Measure III. Treatment adherence was

calculated from attended sessions as a proportion of scheduled sessions, and adverse events were recorded throughout the intervention period, including skin redness, pain-related interruption, and autonomic dysreflexia episodes.

Data were entered and analyzed using SPSS version 26. Continuous variables were summarized as mean and standard deviation, while categorical variables were summarized as frequency and percentage. Baseline demographic and clinical characteristics were described separately for both groups. Within-group changes over time and between-group differences in outcome trajectories were evaluated using repeated-measure comparisons appropriate to the distribution and structure of the data. Between-group comparisons at follow-up were interpreted in relation to baseline comparability and change from baseline. A p-value of less than 0.05 was considered statistically significant. Participants who did not complete the 12-week intervention were documented with reasons for dropout, and the analyzed denominator was reported for each outcome and timepoint to maintain transparency in interpretation.

RESULTS

A total of 40 patients with spinal cord injury were enrolled and allocated equally into the conventional physiotherapy group and the NMES plus conventional physiotherapy group. Four participants did not complete the 12-week intervention period, with two dropouts in each group due to transport-related problems or intercurrent illness. Baseline demographic and clinical characteristics were comparable in distribution between the two groups, although formal between-group statistical comparisons were not available from the supplied dataset.

Table 1. Baseline Demographic and Clinical Characteristics of Participants

Variable	Conventional Physiotherapy (n=20)	NMES + Conventional Physiotherapy (n=20)
Age, years, Mean ± SD	31.8 ± 9.4	30.9 ± 8.7
Male sex, n (%)	15 (75.0)	14 (70.0)
Time since injury, months, Mean ± SD	4.2 ± 1.8	4.5 ± 2.0
Paraplegia, n (%)	12 (60.0)	13 (65.0)
Tetraplegia, n (%)	8 (40.0)	7 (35.0)
Incomplete injury, n (%)	11 (55.0)	12 (60.0)
Baseline quadriceps strength, kg, Mean ± SD	11.4 ± 3.1	11.6 ± 3.0
Baseline SCIM-III score, Mean ± SD	38.2 ± 8.4	37.8 ± 7.9

Abbreviations: NMES, neuromuscular electrical stimulation; SCIM-III, Spinal Cord Independence Measure III; SD, standard deviation.

At baseline, both groups had similar mean age, time since injury, distribution of paraplegia and tetraplegia, incomplete injury status, quadriceps strength, and SCIM-III score. Mean baseline quadriceps strength was 11.4 ± 3.1 kg in the conventional physiotherapy group and 11.6 ± 3.0 kg in the NMES plus conventional physiotherapy group. Baseline SCIM-III scores were also similar, with mean values of 38.2 ± 8.4 and 37.8 ± 7.9, respectively.

Table 2. Baseline-to-Week-12 Changes in Muscle Strength, Muscle Bulk, Spasticity, and Functional Independence

Outcome	Conventional Physiotherapy Baseline	Conventional Physiotherapy Week 12	Conventional Physiotherapy Change	NMES + Conventional Physiotherapy Baseline	NMES + Conventional Physiotherapy Week 12	NMES + Conventional Physiotherapy Change
Quadriceps strength, kg, Mean ± SD	11.4 ± 3.1	14.0 ± 3.9	2.6	11.6 ± 3.0	22.8 ± 4.8	11.2
Thigh circumference, cm, Mean ± SD	39.6 ± 3.8	40.4 ± 3.7	0.8	39.3 ± 3.5	43.1 ± 3.8	3.8
Mid-thigh CSA, cm², Mean ± SD	23.1 ± 4.2	24.2 ± 4.0	1.1	22.8 ± 4.1	28.6 ± 4.7	5.8
Modified Ashworth Scale, Mean ± SD	1.8 ± 0.7	1.7 ± 0.6	-0.1	1.9 ± 0.8	1.5 ± 0.6	-0.4
SCIM-III score, Mean ± SD	38.2 ± 8.4	44.1 ± 8.9	5.9	37.8 ± 7.9	52.3 ± 9.1	14.5

Abbreviations: CSA, cross-sectional area; NMES, neuromuscular electrical stimulation; SCIM-III, Spinal Cord Independence Measure III; SD, standard deviation. Change values were calculated as week-12 value minus baseline value. The supplied dataset did not provide confidence intervals, p-values, or raw data required for valid inferential testing.

Both groups demonstrated improvement from baseline to week 12, but the magnitude of change was larger in the NMES plus conventional physiotherapy group across the main strength, structural, and functional outcomes. Quadriceps strength increased by 2.6 kg in the conventional physiotherapy group and by 11.2 kg in the NMES plus conventional physiotherapy group. Thigh circumference increased by 0.8 cm with conventional physiotherapy and by 3.8 cm with adjunctive NMES. Mid-thigh muscle cross-sectional area increased by 1.1 cm^2 in the conventional physiotherapy group and by 5.8 cm^2 in the NMES group. Functional independence also showed a larger increase in the NMES group, with SCIM-III improving by 14.5 points compared with 5.9 points in the conventional physiotherapy group. Modified Ashworth Scale scores decreased slightly in both groups, with a greater numerical reduction in the NMES group.

Table 3. Between-Group Differences in Baseline-to-Week-12 Change Scores

Outcome	Conventional Physiotherapy Change	NMES + Conventional Physiotherapy Change	Between-Group Difference in Change
Quadriceps strength, kg	2.6	11.2	8.6
Thigh circumference, cm	0.8	3.8	3.0
Mid-thigh CSA, cm^2	1.1	5.8	4.7
Modified Ashworth Scale	-0.1	-0.4	-0.3
SCIM-III score	5.9	14.5	8.6

Abbreviations: CSA, cross-sectional area; NMES, neuromuscular electrical stimulation; SCIM-III, Spinal Cord Independence Measure III. Between-group difference in change was calculated as change in the NMES plus conventional physiotherapy group minus change in the conventional physiotherapy group.

The between-group comparison of change scores showed larger numerical gains with adjunctive NMES. The NMES group demonstrated an additional 8.6 kg improvement in quadriceps strength compared with conventional physiotherapy alone. The corresponding between-group difference in change was 3.0 cm for thigh circumference and 4.7 cm^2 for mid-thigh cross-sectional area. The SCIM-III score improved by an additional 8.6 points in the NMES group compared with the conventional physiotherapy group, indicating a larger functional gain over the 12-week intervention period. The Modified Ashworth Scale showed a small additional reduction of 0.3 points in the NMES group.

Table 4. Treatment Adherence, Dropouts, and Adverse Events

Variable	Conventional Physiotherapy	NMES + Conventional Physiotherapy
Mean attendance rate, %	86	89
Mild skin redness, n	0	4
Treatment stopped due to pain, n	0	1
Autonomic dysreflexia episodes, n	0	0
Dropouts, n	2	2

Abbreviation: NMES, neuromuscular electrical stimulation. Denominators for adverse-event percentages were not specified in the supplied dataset; therefore, percentages were not calculated.

Treatment adherence was high in both groups, with a mean attendance rate of 86% in the conventional physiotherapy group and 89% in the NMES plus conventional physiotherapy group. Four cases of mild skin redness were recorded in the NMES group, and one participant required treatment interruption due to pain. No autonomic dysreflexia episodes were reported in either group. Dropout frequency was equal between groups, with two participants lost from each arm during the 12-week intervention period.

Overall, the available results suggest that adding NMES to conventional physiotherapy was associated with greater numerical improvement in quadriceps strength, thigh circumference, mid-thigh muscle cross-sectional area, and SCIM-III score over 12 weeks compared with conventional physiotherapy alone.

The safety profile was acceptable in the supplied data, with minor skin redness and pain-related interruption reported only in the NMES group and no recorded autonomic dysreflexia episodes.

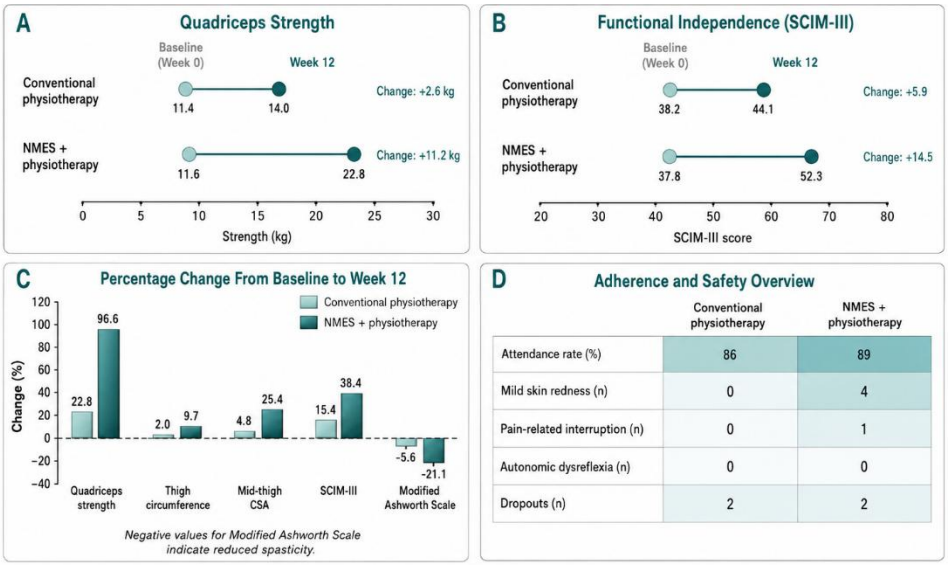

Figure 1 Integrated Outcome Profile of Adjunctive NMES

DISCUSSION

This controlled experimental study found that patients with spinal cord injury who received neuromuscular electrical stimulation in addition to conventional physiotherapy showed greater numerical improvement in quadriceps strength, muscle bulk indicators, and functional independence over 12 weeks than those who received conventional physiotherapy alone. Quadriceps strength increased from 11.6 ± 3.0 kg to 22.8 ± 4.8 kg in the NMES plus physiotherapy group, compared with an increase from 11.4 ± 3.1 kg to 14.0 ± 3.9 kg in the conventional physiotherapy group. Functional independence, measured by SCIM-III, also improved more prominently in the NMES group, rising from 37.8 ± 7.9 to 52.3 ± 9.1, compared with 38.2 ± 8.4 to 44.1 ± 8.9 in the control group. These findings suggest that adjunctive NMES may provide an additional strengthening and rehabilitation stimulus when incorporated into a structured physiotherapy program for patients with spinal cord injury.

The observed strength gains are consistent with the biological rationale for using electrical stimulation in spinal cord injury rehabilitation. After spinal cord injury, lower-limb muscles are exposed to reduced voluntary activation, decreased mechanical loading, altered neural drive, and progressive disuse-related structural changes. NMES can partially address this problem by producing repeated externally evoked contractions in muscles that patients cannot activate effectively through voluntary effort alone. Previous literature has reported that electrical stimulation-based training may support muscle activation, preserve or increase muscle size, and improve selected performance outcomes in individuals with spinal cord injury (1,3,4,9,10). In the present study, the larger gain in quadriceps strength in the NMES group supports the clinical value of adding direct muscle activation to standard rehabilitation, particularly in patients with lower-limb weakness.

The improvement in thigh circumference and ultrasonographic mid-thigh cross-sectional area further supports the interpretation that NMES may have contributed to better local muscle preservation. Thigh circumference increased by 3.8 cm in the NMES group compared with 0.8 cm in the conventional physiotherapy group, while mid-thigh cross-sectional area increased by 5.8 cm^2 and 1.1 cm^2, respectively. These findings are clinically relevant because muscle wasting after spinal cord injury begins early and may reduce the patient's ability to participate in progressive rehabilitation. Studies using electrically stimulated resistance training and cycling have similarly reported favorable changes in skeletal muscle size, muscle performance, and tissue characteristics after spinal cord injury (11–16). Although the

present study did not evaluate metabolic outcomes, the structural changes observed in the NMES group indicate that repeated electrically evoked contractions may help counteract disuse-related muscle loss during the rehabilitation period.

Functional recovery is an important endpoint in spinal cord injury rehabilitation because isolated improvement in muscle strength is clinically meaningful only when it supports activity and independence. In the present study, SCIM-III improved by 14.5 points in the NMES group compared with 5.9 points in the conventional physiotherapy group. This larger functional gain may be explained by improved quadriceps performance, better lower-limb loading capacity, enhanced tolerance for supported standing, and improved participation in transfer-related and task-oriented training. Previous studies on functional electrical stimulation and stimulation-assisted rehabilitation have suggested that electrical stimulation may produce broader functional benefit when combined with purposeful rehabilitation activities rather than used as an isolated modality (18,27). The current findings are therefore most appropriately interpreted as supporting NMES as an adjunct to conventional physiotherapy, not as a replacement for comprehensive rehabilitation.

Spasticity did not worsen during the intervention period. Modified Ashworth Scale scores decreased slightly in both groups, with a greater numerical reduction in the NMES group. This finding is important because clinicians may be concerned that electrical stimulation could increase tone or provoke unwanted reflex activity in patients with spinal cord injury. Published evidence on stimulation and spasticity remains variable, and the effect may depend on stimulation parameters, patient selection, injury characteristics, and monitoring procedures (19,20). In this study, the use of tolerable stimulation intensity, structured on:off cycles, skin monitoring, and supervised application may have contributed to acceptable tolerance. However, because the study did not include detailed spasticity subgroup analysis, the observed reduction should be interpreted cautiously.

The adherence and safety findings support the practical feasibility of NMES in a tertiary rehabilitation setting. Mean attendance was 89% in the NMES group and 86% in the conventional physiotherapy group. Mild skin redness occurred in four patients receiving NMES, and one patient required treatment interruption due to pain. No autonomic dysreflexia episodes were reported. These findings suggest that NMES can be delivered with acceptable short-term safety when patients are screened appropriately and monitored during treatment. Nevertheless, implementation in routine practice requires trained physiotherapists, appropriate electrode placement, regular skin inspection, documentation of tolerance, and careful adjustment of current intensity. This is especially relevant in Pakistani rehabilitation settings, where device availability, patient transport, cost, and follow-up adherence may influence treatment continuity.

The findings have practical relevance for rehabilitation services in Pakistan. Many patients with spinal cord injury present with delayed rehabilitation access, financial limitations, and difficulty attending long-term supervised therapy. NMES is less resource-intensive than many advanced rehabilitation technologies and may be integrated into existing physiotherapy sessions using a focused protocol directed at key muscle groups such as the quadriceps. For tertiary care hospitals, this makes adjunctive NMES a potentially realistic intervention for improving lower-limb muscle performance and functional rehabilitation participation. However, local implementation should be supported by written protocols, therapist training, patient education, and structured adverse-event monitoring.

This study has several limitations. The sample size was small, and the intervention period was limited to 12 weeks. Four participants did not complete the protocol, and the final analysis denominator for each week-12 outcome was not fully specified in the supplied dataset. The method of allocation was not described in sufficient detail to confirm randomization or allocation concealment; therefore, the findings should be interpreted as preliminary controlled experimental evidence rather than definitive randomized trial evidence. The manuscript also did not provide p-values, confidence intervals, effect sizes, or raw data required for robust inferential analysis. In addition, the study included a mixed spinal

cord injury population with variation in injury level, completeness, and chronicity, which may influence response to NMES. Ultrasonographic cross-sectional area is clinically useful but may be less precise than advanced imaging methods such as MRI or CT.

Future studies should use larger multicenter samples, clearly described randomization procedures, concealed allocation, blinded outcome assessment, and prespecified statistical models for repeated-measures data. Stratified analysis by injury completeness, neurological level, and time since injury would help identify which patient groups benefit most from NMES. Longer follow-up is also needed to determine whether strength and functional gains persist after supervised treatment ends. Future Pakistani studies should additionally evaluate patient-reported outcomes, caregiver burden, quality of life, home-based feasibility, and cost-effectiveness so that rehabilitation recommendations are grounded in both clinical and health-system relevance.

CONCLUSION

Neuromuscular electrical stimulation, when added to conventional physiotherapy, was associated with greater numerical improvement in quadriceps strength, thigh circumference, mid-thigh muscle cross-sectional area, and SCIM-III functional independence score over 12 weeks in patients with spinal cord injury. The intervention was generally well tolerated, with minor skin redness and one pain-related interruption reported in the NMES group and no recorded autonomic dysreflexia episodes. These findings support the potential role of adjunctive NMES as a practical, non-invasive rehabilitation strategy for improving muscle performance and functional participation in tertiary spinal cord injury rehabilitation settings. Because the sample was small and allocation procedures and inferential statistics were insufficiently reported, larger rigorously designed controlled trials are required before firm clinical recommendations can be made.

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