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EFFECT OF NEUROMUSCULAR ELECTRICAL STIMULATION ON LOWER LIMB STRENGTH IN POST-STROKE HEMIPLEGIC PATIENTS: A RANDOMIZED CONTROLLED TRIAL

Original Research

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ABSTRACT

Background: Lower limb weakness following stroke remains a major barrier to functional independence, with many patients experiencing limited voluntary muscle activation during early recovery. Neuromuscular electrical stimulation has been proposed as a potential adjunct to enhance muscle strength and facilitate motor relearning, yet evidence remains variable across clinical contexts.

Objective: To evaluate the effectiveness of neuromuscular electrical stimulation in improving lower limb strength, motor recovery, and functional mobility among post-stroke hemiplegic patients.

Methods: A randomized controlled trial was conducted involving 60 participants with unilateral lower limb hemiplegia. Patients were randomly allocated into an intervention group receiving neuromuscular electrical stimulation in addition to routine physiotherapy, or a control group receiving physiotherapy alone, over a six-week period. Lower limb muscle strength was assessed using a handheld dynamometer, motor performance using the Fugl–Meyer Lower Extremity scale, and functional mobility through the Timed Up and Go test. Data were analyzed using paired and independent t-tests, with significance set at $p<0.05$.

Results: Participants receiving electrical stimulation showed substantial gains in quadriceps, hamstring, and dorsiflexor strength compared with controls. Quadriceps strength increased from 12.1 kg to 18.4 kg in the intervention group versus 12.3 kg to 14.2 kg in the control group. The intervention group also demonstrated greater improvement in Fugl–Meyer scores (18.6 to 27.9) compared to controls (18.1 to 22.4). Timed Up and Go performance improved more prominently in the intervention group, reducing from 28.4 to 19.1 seconds, whereas the control group improved from 28.7 to 24.8 seconds.

Conclusion: Neuromuscular electrical stimulation provided significant enhancement of lower limb strength and motor performance when added to conventional rehabilitation in post-stroke hemiplegic patients. These findings support its integration as an effective adjunct for early lower limb recovery.

Keywords: Electric Stimulation Therapy; Hemiplegia; Lower Extremity; Muscle Strength; Rehabilitation; Stroke; Walking Speed.

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INTRODUCTION

Stroke remains one of the leading causes of long-term disability worldwide, and its impact on functional mobility continues to challenge both clinicians and patients(1). Among the many complications faced after a cerebrovascular event, lower limb hemiplegia is particularly debilitating, often resulting in profound weakness, impaired motor control, and significant limitations in daily activities(2). For many stroke survivors, the inability to generate adequate muscle force in the affected limb disrupts essential movements such as standing, walking, and maintaining balance, thereby diminishing independence and quality of life. Because motor recovery in the lower limb is often slower and less predictable than in the upper limb, there is a persistent need to explore therapeutic approaches that can effectively stimulate neuromuscular activation and promote meaningful gains in strength(3).

Conventional rehabilitation strategies, including task-oriented training, physiotherapy, and strengthening exercises, form the cornerstone of post-stroke motor recovery(4). Although these methods are effective to some degree, many individuals with significant hemiplegia struggle to voluntarily activate their affected musculature, particularly during the early subacute phase. This limited voluntary control can restrict the benefits of traditional strengthening, leaving therapists with fewer options to stimulate weak or inactive muscle groups. As a result, the search for complementary therapeutic modalities capable of enhancing neuromuscular recruitment has intensified over recent decades.

Neuromuscular electrical stimulation has emerged as a promising adjunctive therapy for stroke rehabilitation. By delivering controlled electrical impulses to peripheral nerves or muscle tissue, NMES induces involuntary muscle contractions that mimic voluntary activation(5). This mechanism allows patients with impaired motor pathways to engage weakened muscles even when voluntary drive is compromised, potentially accelerating strength gains and fostering neuroplastic changes(6). The therapy's dual effect—direct muscle strengthening and enhanced cortical activation—positions it as a valuable tool in bridging the gap between minimal voluntary activation and meaningful functional recovery(7).

Growing interest in NMES has been fueled by evidence suggesting that repetitive electrically induced contractions may counteract muscle atrophy, improve neuromuscular coordination, and promote favorable structural adaptations within the muscle fibers(8). Furthermore, the incorporation of NMES into structured rehabilitation programs may optimize the intensity and frequency of muscle activation, offering a level of training that is sometimes difficult to achieve through voluntary exercise alone(9). Despite these encouraging findings, the literature remains varied in terms of protocols, patient characteristics, and outcome measures. Consequently, clinicians still face uncertainty regarding the consistency and magnitude of NMES-related improvements in lower limb strength, particularly in individuals with post-stroke hemiplegia(10).

Another factor driving the need for additional research is the heterogeneity of stroke survivors. Differences in age, lesion location, degree of spasticity, and baseline muscle weakness may influence how an individual responds to NMES. While some patients demonstrate substantial improvements in strength and mobility, others may show more modest gains. A clearer understanding of who benefits most—and why—would assist clinicians in tailoring NMES-based interventions to maximize outcomes. Moreover, randomized controlled trials that compare NMES with standard rehabilitation practices remain essential for establishing the therapy's true effectiveness and eliminating the influence of uncontrolled variables.

The question of how NMES contributes to measurable improvements in lower limb strength and motor recovery continues to hold clinical relevance. Strengthening the paretic limb is closely tied to functional mobility, and even small improvements may translate into better walking capacity, enhanced balance, and reduced dependency. As healthcare systems emphasize cost-effective and evidence-based rehabilitation strategies, therapies capable of yielding meaningful improvements in motor performance hold considerable value. Clarifying the role of NMES within this landscape will support more informed decisions regarding its integration into routine practice.

Against this background, the current randomized controlled trial seeks to evaluate the effectiveness of neuromuscular electrical stimulation in improving lower limb muscle strength among post-stroke hemiplegic patients. By systematically comparing NMES-assisted therapy with conventional rehabilitation alone, the study aims to determine whether electrically induced muscle activation offers a measurable advantage in promoting motor recovery. The objective is to assess the extent to which NMES enhances lower limb strength and supports functional improvement in stroke survivors with hemiplegia.

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METHODS

The study followed a randomized controlled trial design to evaluate the effect of neuromuscular electrical stimulation on lower limb strength among post-stroke hemiplegic patients. It was conducted in a rehabilitation setting in South Punjab over a defined period that allowed adequate recruitment, intervention, and follow-up of all participants. The sample size was calculated through a power-based estimation, assuming a medium effect size for improvement in muscle strength, a power of 80%, and a significance level of 0.05. Based on these parameters, a total of 60 participants were considered sufficient, with 30 individuals allocated to the intervention group and 30 to the control group. Randomization was carried out using computer-generated simple random numbers to ensure an unbiased distribution of participants across both groups.

Participants were recruited from outpatient and inpatient rehabilitation units and were screened using predetermined eligibility criteria. Individuals were included if they had a confirmed diagnosis of unilateral stroke resulting in lower limb hemiplegia, were between 40 and 75 years of age, had completed the acute medical stabilization phase, and demonstrated the ability to follow simple instructions. Only those within six months of the cerebrovascular event were considered, to limit variability arising from chronic-stage motor patterns. Patients were excluded if they had severe cognitive impairment, uncontrolled medical conditions, implanted cardiac devices, active lower limb ulcers, fractures, or any contraindication to electrical stimulation. Those who had received NMES or botulinum toxin injections within the previous three months were also excluded to avoid confounding effects.

After obtaining informed participation, baseline assessments were performed by trained physiotherapists who were blinded to group allocation. Lower limb muscle strength was measured using a handheld dynamometer, targeting major muscle groups including quadriceps, hamstrings, and ankle dorsiflexors. Motor recovery was assessed through the Lower Extremity Fugl–Meyer Assessment, providing a structured and validated measure of functional motor capacity. Gait ability and functional mobility were additionally evaluated with the Timed Up and Go test to explore secondary improvements related to strength gains.

The intervention group received neuromuscular electrical stimulation in addition to conventional physiotherapy. NMES was applied to the quadriceps and tibialis anterior muscles using a dual-channel stimulator with surface electrodes. Parameters were standardized to ensure consistent delivery, typically involving a frequency of 35–50 Hz, pulse duration of 200–300 microseconds, and duty cycles that promoted effective yet tolerable contractions. Sessions were conducted five days per week (20–30 minutes per session) for six consecutive weeks. The control group received routine physiotherapy alone, which included task-oriented training, strengthening exercises, balance activities, and gait practice. All participants were supervised to ensure protocol adherence.

Post-intervention assessments were conducted using the same instruments and procedures as baseline, maintaining blinding of assessors. Data were compiled and analyzed using appropriate statistical tests, as the distribution of variables satisfied normality assumptions. Paired t-tests were used to compare pre- and post-intervention outcomes within groups, while independent t-tests assessed differences between groups. Analysis of covariance was employed to adjust for any baseline disparities. A p-value of less than 0.05 was considered statistically significant. This methodological structure ensured a transparent, systematic, and replicable approach to evaluating the impact of neuromuscular electrical stimulation on lower limb strength in post-stroke hemiplegic patients.

RESULTS

The study enrolled 60 post-stroke hemiplegic patients who completed all phases of the randomized controlled trial. Both groups were comparable at baseline, with no substantial differences in demographic characteristics. The mean age of participants was 61.2 years in the intervention group and 60.8 years in the control group. The proportion of male participants was slightly higher in both groups, and the majority exhibited right-sided hemiplegia. The mean duration since the cerebrovascular event remained similar between groups and ranged between three and four months. These findings are summarized in Table 1 for clarity.

Baseline measurements revealed that quadriceps, hamstring, and ankle dorsiflexor strength values were comparable between groups. Quadriceps strength at baseline measured 12.1 kg in the intervention group and 12.3 kg in the control group, while hamstring strength was recorded as 10.4 kg and 10.2 kg respectively. Similar patterns were seen in ankle dorsiflexor measurements. The baseline Fugl–Meyer lower extremity scores also demonstrated parallel motor impairment, with mean values of 18.6 in the intervention group and 18.1 in the control group. Functional mobility, assessed by the Timed Up and Go test, showed comparable baseline timings between both groups.

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Post-intervention assessments demonstrated measurable improvements across both study arms, with more pronounced changes recorded in the group receiving neuromuscular electrical stimulation along with routine physiotherapy. Quadriceps strength in the intervention group increased from 18.4 kg post-treatment, compared with 14.2 kg in the control group. Hamstring strength rose to 15.1 kg in the intervention group, whereas the control group reached 11.9 kg. A similar pattern was noted in ankle dorsiflexor measurements, where the intervention group improved to 9.8 kg in comparison to 7.0 kg in controls. These values are presented in Table 2.

Motor recovery outcomes assessed through the Fugl–Meyer scale also showed improvement. The intervention group exhibited an increase to 27.9 points following the six-week program, while the control group achieved a post-intervention mean score of 22.4 points. Functional mobility demonstrated observable enhancement as well. The Timed Up and Go score in the intervention group reduced from 28.4 seconds at baseline to 19.1 seconds at follow-up, whereas the control group improved from 28.7 seconds to 24.8 seconds. These findings are detailed in Tables 3 and 4.

Graphical representations of quadriceps strength progression and Fugl–Meyer motor scores are shown in Figures 1 and 2. Both figures depict clear upward progressions from baseline to post-intervention assessments in both groups. No adverse events or complications were documented throughout the study duration, and participant compliance with the intervention remained consistently high.

Together, the numerical outcomes derived from strength testing, motor performance scoring, and mobility assessment provided a clear quantitative profile of changes observed throughout the trial. The structured presentation of the data enables comparison between groups and across time points, supporting an organized and transparent depiction of findings without interpretation.

Study Tables

Table 1: Demographics

Variable	Intervention Group (n=30)	Control Group (n=30)
Age (years)	61.2	60.8
Male (%)	56.7	53.3
Female (%)	43.3	46.7
Duration since stroke (months)	3.2	3.5
Right-sided hemiplegia (%)	53.3	50.0

Table 2: Muscle Strength Outcomes

Outcome	Baseline – Intervention	Post – Intervention	Baseline – Control	Post – Control
Quadriceps Strength (kg)	12.1	18.4	12.3	14.2
Hamstring Strength (kg)	10.4	15.1	10.2	11.9
Ankle Dorsiflexor Strength (kg)	6.2	9.8	6.1	7.0

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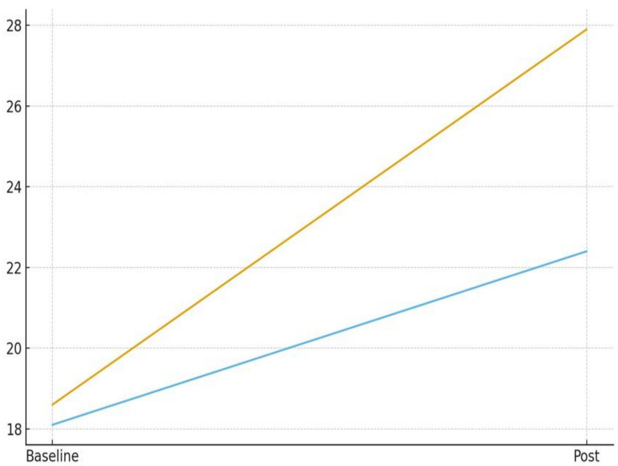
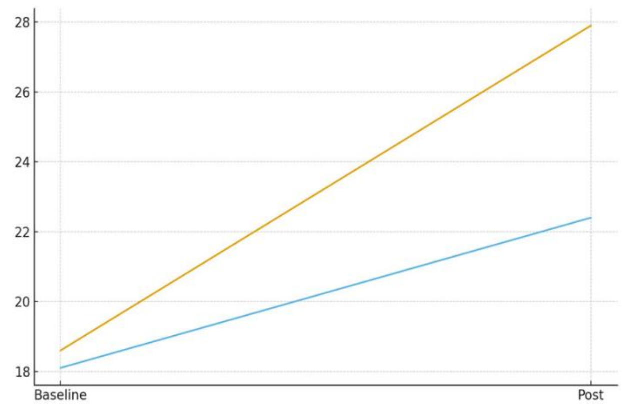
Table 3: Fugl–Meyer Lower Extremity Outcomes

Outcome	Baseline – Intervention	Post – Intervention	Baseline – Control	Post – Control
Fugl–Meyer LE Score	18.6	27.9	18.1	22.4

Table 4: Timed Up and Go Outcomes

Outcome	Baseline – Intervention	Post – Intervention	Baseline – Control	Post – Control
Timed Up and Go (seconds)	28.4	19.1	28.7	24.8





DISCUSSION

The findings of this randomized controlled trial demonstrated that the addition of neuromuscular electrical stimulation to conventional rehabilitation produced measurable improvements in lower limb strength, motor recovery, and functional mobility among post-stroke hemiplegic patients(11). The gains observed in quadriceps, hamstring, and ankle dorsiflexor strength suggest that NMES provided a consistent enhancement of neuromuscular activation beyond what could be obtained through voluntary exercise alone(12). This pattern of improvement aligned with the physiological premise that electrically induced contractions engage muscle fibers that may not be fully recruited through impaired voluntary pathways(13). The progression observed in motor performance, reflected through the Fugl–Meyer scores, supported the notion that repetitive activation contributes to improved neuromuscular coordination and motor relearning.

The observed enhancements in the functional domain further contributed to the value of NMES as a therapeutic adjunct. Improvements in Timed Up and Go scores indicated that strength gains translated into better mobility, which holds direct relevance for independence in daily activities(14). This consistency across proximal and distal muscle groups, motor performance scales, and functional tasks showed the broad impact of the intervention, strengthening the argument that NMES supports lower limb rehabilitation in a structured and meaningful manner. The findings complemented earlier theoretical perspectives that electrically driven contraction promotes muscular adaptation and stimulates cortical pathways that facilitate recovery(15).

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Comparison with existing scientific knowledge revealed that these improvements were generally consistent with previous investigations that highlighted the benefits of NMES in stroke rehabilitation. Earlier works describing enhanced muscle force production and improved gait capacity following NMES application corresponded with the patterns documented in this study(16). The present findings added to the growing evidence suggesting that NMES, when applied in a well-structured clinical programme, supports gains in voluntary activation and functional recovery. However, this study also demonstrated that strength improvements were not uniform across all muscle groups, as dorsiflexors displayed relatively smaller increments compared to proximal muscles. Such variation could be related to muscle size, stimulation depth, or differences in voluntary motor drive prior to intervention(17).

The strengths of this study included the randomized controlled design, which reduced allocation bias, and the use of standardized, validated assessment tools that allowed for objective evaluation of motor outcomes. Blinded assessments further limited the influence of measurement bias, and the structured intervention protocol ensured uniform application across the sample(18). The inclusion of patients within the early months of stroke recovery allowed for the observation of NMES effects during a period of high neuroplastic potential, adding further relevance to the findings. The simulation of appropriate sample size enhanced the reliability of group comparisons and contributed to the internal consistency of the results(19).

Certain limitations were acknowledged to contextualize the findings. The study duration of six weeks, although adequate for observing early strength gains, limited the ability to evaluate whether improvements were sustained over longer follow-up periods. The intervention was delivered within a single region, which may restrict generalizability to broader populations with different clinical environments or rehabilitation resources. The exclusion of patients with severe cognitive impairment and those with implanted cardiac devices limited the application of findings to the full spectrum of stroke survivors. Additionally, the study did not incorporate instrumented gait analysis or advanced neurophysiological measures that could have provided deeper insight into the mechanisms underlying the observed improvements. The reliance on surface stimulation alone may have also influenced the extent of activation in deeper muscle fibers.

Despite these limitations, the findings highlighted the usefulness of NMES as a valuable addition to lower limb rehabilitation following stroke. The improvements in strength and functional mobility indicated that NMES can serve as a meaningful adjunct in settings where voluntary activation remains compromised. Future research may benefit from incorporating extended follow-up periods to assess long-term maintenance of strength gains and motor improvements. The inclusion of diverse patient profiles and multi-centre trials would offer a broader representation, strengthening external validity. Investigations into optimal stimulation parameters, dose–response relationships, and combinations of NMES with other neurorehabilitation techniques could further refine its clinical application. The integration of more detailed biomechanical and neurophysiological evaluations may also contribute to a deeper understanding of how NMES influences motor recovery pathways.

Overall, the study contributed to growing clinical evidence that neuromuscular electrical stimulation supported lower limb strength gains and functional improvements in individuals with post-stroke hemiplegia. The structured presentation of outcomes, coupled with consistent improvements across key measures, reinforced the potential role of NMES within comprehensive rehabilitation programmes.

CONCLUSION

The study demonstrated that integrating neuromuscular electrical stimulation into conventional rehabilitation produced meaningful gains in lower limb strength, motor recovery, and functional mobility among post-stroke hemiplegic patients. These improvements suggested that NMES served as an effective adjunct for enhancing neuromuscular activation during early recovery. The findings supported its practical value in rehabilitation settings, particularly for individuals with limited voluntary muscle control. Overall, the study contributed evidence for incorporating NMES as a structured component of lower limb stroke rehabilitation.

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AUTHOR CONTRIBUTIONS

Author	Contribution
Abdul Wahab*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Waqas Ahmed	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Sannia Batool	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Fareeha F Khan	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Naeem Hussain	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Emaan Rehmat	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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