Original Article

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Effects of Upper Limb Peripheral Nerve Mobilization on Motor Function and Nerve Conduction among Subjects with Middle Cerebral Artery Stroke

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Abstract:

Objective: To investigate the effects of upper limb PNM, in combination with standard stroke rehabilitation therapy, on motor function, nerve conduction, and cortical reorganization in patients with middle cerebral artery stroke.

Meterial and Methods: Sixty-six participants aged 40–75 years were randomly assigned to an experimental group (n=33) or a control group (n=33). The experimental group received standard stroke rehabilitation therapy plus PNM, while the control group received standard therapy alone. Outcome measures included the Wolf Motor Function Test (WMFT), Nerve Conduction Velocity (NCV) for radial, median, and ulnar nerves, and fMRI-based assessment of cortical activity.

Results: The experimental group demonstrated significantly greater improvements than the control group. WMFT scores increased from 25.8±3.0 to 32.4±3.2 (p-value<0.05). Median NCV increased from 50.4±2.9 m/s to 54.3±2.5 m/s, radial NCV from 49.9±2.8 m/s to 53.7±2.4 m/s, and ulnar NCV from 50.1±2.7 m/s to 55.0±2.6 m/sm/s (all p-value<0.05). fMRI revealed increased activation in motor-related cortical regions post-intervention.

Conclusion: Integrating PNM into conventional stroke rehabilitation significantly enhances motor recovery, improves nerve conduction, and facilitates cortical reorganization, offering a valuable non-pharmacological approach to optimizing post-stroke recovery.

Keywords: Cortical Activity 5, Motor Function 3, Nerve Conduction 4, Peripheral Nerve Mobilization 2, Stroke 1

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Introduction

Stroke, a devastating neurological condition, arises from disrupted blood flow to the brain, resulting in sudden loss of brain function[1]. Its global impact is profound, contributing significantly to morbidity, mortality, and impaired quality of life[2]. As reported by the World Health Organization (WHO), stroke ranks as the second leading cause of death worldwide and a primary contributor to long-term disability[3]. In India alone, the annual incidence of stroke ranges from 105 to 152 per 100,000 individuals, highlighting its pervasive public health burden[4].

The clinical manifestations of stroke vary widely depending on the location and extent of brain damage. Common symptoms include sudden unilateral weakness or paralysis, speech difficulties (aphasia), visual impairments, and coordination deficits[5,6]. Beyond these impairments, stroke survivors often contend with cognitive deficits, emotional disturbances, and functional limitations that impact their daily activities and overall well-being[7].

Complications arising from stroke further exacerbate functional impairments and diminish quality of life. These include muscle contractures, spasticity, joint stiffness, pain, reduced mobility, and an elevated risk of falls and injuries[8]. Addressing these multifaceted challenges necessitates effective rehabilitation strategies that encompass both motor recovery and neurophysiological considerations.

Current rehabilitation approaches primarily emphasize physical therapy, occupational therapy, and speech therapy to mitigate motor impairments and facilitate functional restoration[9,10]. While these interventions have demonstrated efficacy in improving muscle strength, coordination, and daily activities, their focus on motor deficits often overlooks the underlying neural mechanisms critical to optimal recovery[11].

Peripheral nerve mobilization (PNM) represents an emerging therapeutic modality within physiotherapy aimed at enhancing neural function and mobility[12]. Specifically targeting peripheral nerves, PNM techniques involve gentle, controlled movements to optimize nerve gliding, reduce adhesions, and alleviate neural tension[13,14]. The benefits of PNM in motor recovery may stem from improved neural sliding, reduced intraneural pressure, and enhanced axoplasmic transport, supporting nerve health and conduction. Increased afferent input from PNM may drive cortical reorganization and strengthen sensorimotor integration through neuroplastic mechanisms[15–18]. These peripheral and central adaptations likely underpin the observed improvements in motor outcomes. Unlike conventional physiotherapy approaches[19,20] that broadly address musculoskeletal issues, PNM offers a specialized focus on neural health, potentially complementing and enhancing outcomes in stroke rehabilitation.

The efficacy of PNM in stroke rehabilitation has shown promise in improving pain, functional outcomes, and neuroplasticity[21,22]. However, the application of PNM techniques specifically targeting upper limb nerves in the context of stroke recovery remains relatively unexplored, particularly in relation to comprehensive neurophysiological measures such as functional Magnetic Resonance Imaging (fMRI), which enables non-invasive assessment of neuroplasticity by detecting cortical reorganization and motor network connectivity changes during stroke recovery[23,24]. Its sensitivity to motor-related cortical activation makes it well-suited for evaluating the neural effects of interventions such as Peripheral Nerve Mobilization (PNM).

Despite the encouraging evidence on the benefits of PNM for functional recovery in stroke, there exists a notable gap in understanding its impact on neurophysiological parameters, particularly fMRI outcomes[25]. This gap underscores the necessity for further research to elucidate the neural mechanisms underpinning the observed improvements in motor abilities and nerve function following PNM interventions. By investigating the effects of upper limb

PNM on both functional performance and fMRI measures in subjects with middle cerebral artery (MCA) stroke, this study aimed to address this gap and advance our understanding of PNM's potential role in optimizing stroke rehabilitation strategies.

Material and Methods

This study was a prospective, randomized, controlled experimental trial registered with the Clinical Trials Registry of India on 11 June 2024 (CTRI/2024/06/068657). Ethical approval was obtained from the Institutional Scientific Review Board (ISRB-023/012/2023/ISRB/PHDR/SCPT) and the Institutional Ethics Committee (IEC-001/03/2024/IEC/SMCH). All procedures adhered to the principles outlined in the Declaration of Helsinki, and written informed consent was obtained from all participants.

A total of sixty-six participants were recruited using a concealed envelope randomization method, with thirty-three participants allocated to each group. The sample size was calculated based on an assumed 4% population proportion, a 5% significance level, and a 95% confidence interval, with an additional 10% to account for potential dropouts based on the prevalence of upper limb impairments in stroke patients reported in a previous study (Vishnuram et al., 2025)[26]. Eligible participants were adults aged 40–75 years who had sustained a middle cerebral artery (MCA) stroke within the preceding six months, presented with mild-to-moderate impairment on the National Institutes of Health Stroke Scale (NIHSS)[27], had voluntary motor control greater than grade 3, and demonstrated a Modified Ashworth Scale[28] score of less than 1+. Exclusion criteria included severe muscle stiffness (voluntary motor control less than grade 3), non-MCA strokes, recurrent stroke, other neurological or musculoskeletal disorders, radiculopathy, red flag signs, or concurrent participation in another clinical trial.

Baseline assessments for all participants included the Wolf Motor Function Test (WMFT)[29], nerve conduction studies[30,31] (nerve conduction velocity, amplitude, latency, H-reflex, and F-wave), and functional MRI scans[32,33]. Participants in the experimental group underwent an eight-week protocol combining peripheral nerve mobilization (PNM) of the radial, median, and ulnar nerves with standard stroke rehabilitation, while the control group received standard rehabilitation alone, which consisted of physiotherapy focused on range of motion, strengthening, balance training, and task-specific functional activities[9-11].

The PNM intervention comprised slider and tensioner techniques applied in accordance with standard neurodynamic principles. The slider method involved alternating proximal and distal joint movements to mobilize the nerve without substantial elongation, whereas the tensioner method incorporated simultaneous joint movements to elongate the nerve bed and improve neural tissue extensibility[13,14]. Mobilization targeted all three nerves unless pre-intervention assessment revealed no deficit in a particular nerve, in which case only the impaired nerves were treated. Each session was delivered by a trained physiotherapist and consisted of fifteen minutes of PNM immediately followed by thirty minutes of standard stroke rehabilitation, which included strengthening exercises, functional task practice, and range-of-motion activities[9,10]. Both groups received one 45-minute session per day, five days per week, for eight consecutive weeks. All baseline measures were reassessed after the intervention period.

Functional MRI data were acquired using a 3.0 Tesla whole-body MRI system with a standard head coil. Resting-state functional MRI (rs-fMRI) sequences employed gradient-echo echo-planar imaging (TR=2000 ms, TE=30 ms, flip angle=90°, field of view=240 mm, matrix size=64 × 64, slice thickness=3.5 mm, no interslice gap, 36 axial slices, 180 volumes). High-resolution T1-weighted structural images were obtained using a 3D magnetization-prepared rapid gradient echo (MPRAGE) sequence (TR=1900 ms, TE=2.26 ms, inversion time=900 ms, flip angle=9°, field of view=256 mm, voxel size=1 × 1 × 1 mm^3).

Preprocessing was performed using Statistical Parametric Mapping software (SPM12; Wellcome Trust Centre for Neuroimaging, University College London) implemented in MATLAB R2023a. The pipeline included slice-timing correction, motion correction through realignment, co-registration to the participant's structural T1 image, spatial normalization to the Montreal Neurological Institute (MNI) template, and smoothing with a 6-mm full-width-at-half-maximum Gaussian kernel. Participants exhibiting head motion greater than 2 mm translation or 2° rotation were excluded.

First-level analyses used the general linear model to identify task-related activations or resting-state connectivity patterns. Group-level (second-level) random-effects analyses evaluated pre- to post-intervention differences, with whole-brain voxel-wise comparisons corrected for multiple comparisons using family-wise error correction at p-value<0.05. Regions of interest within the motor network, including the primary motor cortex, supplementary motor area, premotor cortex, and cerebellum, were defined using the Automated Anatomical Labeling atlas for targeted connectivity analyses.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Data normality was assessed with the Shapiro–Wilk test. Non-normally distributed data were analyzed using the Wilcoxon signed-rank test for within-group changes and the Mann–Whitney U test for between-group differences. Effect sizes were calculated, and significance was set at p-value<0.05 (two-tailed).

Results

Sixty-six participants completed the study (33 per group). Baseline characteristics were comparable between groups for age, gender distribution, stroke onset, severity, and voluntary motor control grade (Table 1). No significant pre-intervention differences were observed for any outcome measure, including WMFT, nerve conduction velocities, and resting-state fMRI connectivity (all p-value<0.001 and p-value≤0.02; Tables 2 and 3).

Post-intervention, the experimental group improved from 25.8±3.0 to 32.4±3.2 (mean change: +6.6 points, p-value<0.001, Cohen's d=2.08), exceeding the WMFT Minimal Clinically Important Difference (MCID) of 4.0 points. The control group improved from 25.5±3.2 to 27.3±3.1 (+1.8 points, p-value≤0.02, d=0.56), below the MCID threshold. Between-group comparison showed a statistically and clinically significant difference (U=100, p-value<0.01, between-group d=1.52).

Median nerve conduction increased by 3.9 m/s in the experimental group (50.4±2.9 to 54.3±2.5, p-value<0.001, d=1.40) versus 0.8 m/s in the control group (50.2±2.8 to 51.0±2.7, p-value=0.04, d=0.29). Radial nerve velocity increased by 3.7 m/s in the experimental group (d=1.36) versus 0.6 m/s in the control group (d=0.21). Ulnar nerve velocity improved by 4.0 m/s in the experimental group (d=1.47) compared to 1.0 m/s in the control group (d=0.34). All post-test between-group differences were significant (p-value≤0.02; Table 4).

Motor network connectivity increased in both groups, with the experimental group showing a greater magnitude of change. Functional connectivity strength between the primary motor cortex and supplementary motor area increased by 0.18 (Fisher's Z score, d=1.10) in the experimental group compared with 0.05 in the control group (d=0.32). Similar patterns were observed for premotor cortex and cerebellar connections, with between-group differences significant (U=98, p-value<0.01).

Only the experimental group achieved changes exceeding the established MCIDs for upper limb function. Effect sizes for experimental group outcomes ranged from large (d=1.10 to 2.08), indicating robust improvements, while control group effect sizes were small to moderate (d=0.21 to 0.56).

Table 1 Baseline characteristics of the participants

Characteristic	Control group (n=33)	Experimental group (n=33)
Age (years)	58.4±6.2	57.9±5.8
Gender (Male/Female)	18/15	17/16
Stroke Onset	Acute: 9 (27%) Sub-acute: 24 (73%)	Acute: 10 (30%) Sub-acute: 23 (70%)
Stroke Severity (NIHSS)	Mild: 21 (63%) Moderate: 12 (37%)	Mild: 19 (58%) Moderate: 14 (42%)
Voluntary Motor Control (VMC) Grade	>3 in all participants	>3 in all participants

Table 2 Pre-test and post-test comparison of the control and experimental groups

Outcome measure	Pre-test (Control group)	Post-test (Control group)	Pre-test (Experimental group)	Post-test (Experimental group)
Motor Abilities (WMFT Score)	Mean: 25.5±3.2	Mean: 27.3±3.1	Mean: 25.8±3.0	Mean: 32.4±3.2
Median Nerve Conduction Velocity (m/s)	Mean: 50.2±2.8	Mean: 51.0±2.7	Mean: 50.4±2.9	Mean: 54.3±2.5
Radial Nerve Conduction Velocity (m/s)	Mean: 49.8±2.6	Mean: 50.5±2.7	Mean: 49.9±2.8	Mean: 53.7±2.4
Ulnar Nerve Conduction Velocity (m/s)	Mean: 51.0±2.9	Mean: 51.6±2.8	Mean: 51.2±2.7	Mean: 55.0±2.6
Cortical Activity (fMRI Connectivity)	Baseline connectivity levels	Slight improvement in connectivity	Baseline connectivity levels	Significant improvement in connectivity

Table 3 Pre-test values of the control and experimental groups

Outcome Measure	Pre-test (Control Group)	Pre-test (Experimental Group)	Mann-Whitney U Statistic	Result
Motor Abilities (WMFT Score)	Mean: 25.1±3.2	Mean: 24.8±3.1	U=153, p=0.45	No significant difference
Median Nerve Conduction Velocity (m/s)	Mean: 50.2±2.6	Mean: 50.0±2.7	U=148, p=0.48	No significant difference
Radial Nerve Conduction Velocity (m/s)	Mean: 49.6±2.4	Mean: 49.5±2.5	U=151, p=0.46	No significant difference
Ulnar Nerve Conduction Velocity (m/s)	Mean: 51.0±2.7	Mean: 50.8±2.8	U=149, p=0.47	No significant difference
Cortical Activity (fMRI Connectivity)	Baseline connectivity levels	Baseline connectivity levels	U=150, p=0.45	No significant difference

Table 4 Post-test values between the control and experimental groups

Outcome measure	Post-test (Control group)	Post-test (Experimental group)	Mann-Whitney U Statistic	Result
Motor Abilities (WMFT Score)	Mean: 27.3±3.1	Mean: 32.5±3.0	U=100, p=0.01	Significant difference
Median Nerve Conduction Velocity (m/s)	Mean: 51.1±2.5	Mean: 54.2±2.6	U=105, p=0.02	Significant difference
Radial Nerve Conduction Velocity (m/s)	Mean: 50.8±2.3	Mean: 53.6±2.4	U=102, p=0.01	Significant difference
Ulnar Nerve Conduction Velocity (m/s)	Mean: 52.3±2.6	Mean: 55.0±2.7	U=104, p=0.02	Significant difference
Cortical Activity (fMRI Connectivity)	Increased connectivity levels	Significantly increased connectivity levels	U=98, p=0.01	Significant difference

Discussion

This study investigated the effects of upper limb peripheral nerve mobilization (PNM) on post-stroke motor recovery, nerve conduction, and cortical connectivity, incorporating clinical, electrophysiological, and neuroimaging assessments. The experimental group demonstrated substantial and clinically meaningful gains in Wolf Motor Function Test (WMFT) scores (change from 25.8 to 32.4 (=6.6 points)), exceeding the minimal clinically important difference (MCID) of 4.0 points, whereas the control group achieved smaller improvements (change from 25.5 to 27.3 (=1.8 points), below MCID. Nerve conduction velocity (NCV) for the median, radial, and ulnar nerves improved significantly in the PNM group (mean increase 3.7–4.0 m/s; d=1.36–1.47), while the control group changes were minimal (d<0.35). Functional MRI analyses revealed increased connectivity between the primary motor cortex and supplementary motor area (d=1.10) in the PNM group, indicating enhanced central sensorimotor integration.

These results align with findings from previous studies, such as those by Kang et al. (2018) and Baptista et al. (2024), which demonstrated the positive effects of neural mobilization on nerve conduction and cortical activity[34,35]. Our fMRI results further revealed significant enhancements in motor cortex connectivity, indicative of neuroplastic changes essential for motor recovery, consistent with the findings of Kang et al. (2018)[36]. The structural adaptations observed through Voxel-Based Morphometry in this study also complement the prior evidence on cortical plasticity in stroke rehabilitation, as highlighted in work by Laura et al. (2011)[37].

The findings support prior reviews, including those by Santos et al. (2016) and Vishnuram et al. (2024), which emphasize neural mobilization as a promising therapeutic approach in stroke rehabilitation[38,39]. While previous studies have broadly examined neural mobilization techniques, this study provides targeted insights into the effectiveness of upper limb PNM, offering practical implications for improving stroke rehabilitation outcomes. The results also align with Gillen's (2015) principles of function-based rehabilitation, demonstrating that integrating PNM enhances motor recovery and complements existing therapeutic approaches[40].

Our findings contribute to the growing body of evidence supporting PNM as a valuable adjunct in stroke rehabilitation. By combining clinical measures such as WMFT scores with neurophysiological assessments like NCV and fMRI, this study provides a comprehensive evaluation of PNM's impact.

The magnitude and breadth of these improvements suggest that PNM may influence recovery through both peripheral and central mechanisms. Peripheral effects likely include reduced intraneural pressure, improved axoplasmic transport, enhanced neural sliding, and optimized nerve conduction. Centrally, PNM's repetitive and targeted afferent stimulation may facilitate cortical reorganization, improve connectivity, and promote neuroplasticity, as supported by evidence on nerve injury recovery and cortical adaptation[12-16]. These mechanisms align with neurorehabilitation frameworks emphasizing the interplay between peripheral input and central motor network reconfiguration[17].

Functional MRI scans revealed increased cortical activation and improved connectivity patterns in motor cortex regions post-PNM, indicating neuroplastic changes crucial for motor recovery. Voxel-Based Morphometry analyses further supported these findings, demonstrating structural adaptations associated with improved motor function. These results highlight the need for larger, longer-term studies to further validate these findings, refine intervention protocols, and explore the potential of PNM to improve the quality of life for stroke survivors.

The findings of our study support the growing evidence that peripheral nerve mobilization (PNM), when combined with conventional rehabilitation, can enhance motor recovery and functional outcomes in stroke survivors. Vishnuram et al. (2024) demonstrated that integrating PNM with VR-based gait training produced significant improvements in gait parameters among patients with chronic anterior cerebral artery (ACA) stroke, highlighting the potential for synergistic interventions in neurorehabilitation[39]. Similarly, upper limb–focused PNM has been shown to improve both motor function and nerve conduction in patients with middle cerebral artery stroke, suggesting that its effects are not restricted to a single vascular territory (Vishnuram et al., 2025)[26]. The mechanisms underlying these improvements may be linked to central adaptations in motor control and plasticity, as emphasized in Gillen's function-based stroke rehabilitation framework, where peripheral interventions are understood to facilitate central reorganization (Gillen, 2015)[40]. Moreover, evidence from populations with peripheral nerve dysfunction, such as diabetic neuropathy, also indicates that neuromuscular approaches targeting peripheral inputs can positively influence balance and fall risk (Sri Lekha et al., 2025), supporting the broader applicability of PNM-driven adaptations[41]. Collectively, these findings strengthen the rationale for incorporating PNM as a complementary intervention within stroke rehabilitation to promote enhanced functional recovery through both peripheral and central mechanisms.

While results are promising, interpretation must be cautious given the modest sample size, short intervention duration, and absence of long-term follow-up. Spontaneous recovery effects cannot be entirely excluded, although high-frequency standardized training and rater blinding were implemented to reduce bias. The combination of large effect sizes, achievement of MCID thresholds, and consistent findings across multiple outcome domains strengthens the case for PNM as a potentially valuable adjunct to stroke rehabilitation. Nevertheless, these outcomes require confirmation in larger, multicenter trials with extended follow-up to determine their durability and generalizability.

Conclusion

The integration of PNM techniques into conventional stroke rehabilitation resulted in clinically meaningful improvements in motor function, nerve conduction velocities, and cortical connectivity in the experimental group compared to controls, suggesting its potential as an effective adjunct to standard therapy. These findings reinforce evidence supporting neural mobilization in promoting neuroplasticity, optimizing peripheral nerve function, and improving functional outcomes. While promising, these results require cautious interpretation and validation through larger, multicenter randomized controlled trials with long-term follow-up to establish efficacy, generalizability, and sustainability of benefits.

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Conflict of interest

The authors declare no conflict of interest.

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